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IMPACT OF REPEATED APPLICATIONS OF MANURE AND BIOGAS PRODUCTION BY-PRODUCTS ON SOILS AND CROPS

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Impact of Repeated Applications of Manure and Biogas Production By-Products on Soils and Crops

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Dr. Jeff Schoenau, Principle Investigator, Tom King, PhD student, Dept. of Soil Science, University of Saskatchewan

Dr. S.S.Malhi, Collaborator, Agriculture and Agri-Food Canada Melfort Research Station

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Summary

In the spring of 2007, a new experiment was set up near Dixon SK to look at crop response to manure biodigestate that is produced from biogas production in comparison to conventional liquid manure and urea fertilizer. Three rates of digestate and liquid hog manure (1500, 3000 and 6000 gallons per acre) were applied along with three rates of urea: 50, 100 and 200 lbs N/acre. On the long-term manure monitoring experiments at Dixon, fifteen treatments of liquid swine manure and twelve cattle manure treatments were applied by PAMI, continuing the sequence applied for the previous ten years. At the Melfort long-term liquid swine manure injection site, five treatments involving different rates and sequences of liquid swine manure were applied, with and without sulfur fertilizer as in the previous seven years. In 2007, oats were grown on the plots at Dixon while barley was grown at Melfort. Manure applications were made in late fall of 2007 for the 2008 season. In 2008, canola was grown on the plots at all sites. In the fall of 2008, manure applications were made at all sites for the 2009 season. In 2009, oats were grown on the biodigestate versus raw liquid swine manure site at Dixon and the long-term liquid swine manure site at Melfort. Barley was grown on the long-term manure trials at Dixon in 2009. Assessments of grain and straw yield, nutrient concentrations, soil nutrients and properties were made on plant and soil samples collected every fall in 2007, 2008 and 2009.

Significant yield responses to manure application were observed in 2007 for both the oats and barley. There appeared to be little difference in behavior of the manure digestate compared to the conventional liquid manure in terms of yield responses observed. Annual applications of ~ 3000 gallons per acre (~ 34,000 litres/ha, 70-100 kg total N/ha) as liquid hog manure and biodigestate resulted in maximum yield at all sites. This supports the concept that rates of addition of liquid swine manure in the order of 3000 – 4000 gallons per acre per year is the "agronomic or 1X rate". Higher rates of application (6000 gpa or 2X) made in the previous year showed good carryover into the next year. A rate of ~ 7 tons/acre of penning cattle manure (dry weight basis) applied annually gave the highest yields in the cattle manure trials. In 2007, the highest rates of application of biodigestate, swine and cattle manure (4Xagronomic rate) generally had reduced yield compared to the 2X and 1X rates.

In 2008 a strong yield response of canola to manure application was noted at all sites. Annual applications of swine and cattle manure at 2X and 4X rates tended to produce the highest yields, likely reflecting better growing conditions than in 2007 and also the greater nutrient requirements of canola as compared to the oats and barley grown at the sites in 2007. However, application at the 4X rate (13200 gpa) every year results in excessive soil nitrate levels. As in previous years, there was no difference in agronomic effect of the biodigestate liquid swine manure compared to the raw liquid manure. As well, the addition of the nitrification inhibitor to liquid swine manure had no significant effect on yield. Injection of liquid swine manure produced superior yields compared to broadcast and incorporate. Of note in 2008 was the very large response of canola yield to phosphorus fertilizer application in the urea plots at Dixon and to sulfur fertilizer application at Melfort. However, the liquid swine manure appears to supply close to sufficient amounts of P and S, as response of the liquid manure treatments to supplemental P and S was muted in 2008.

In 2009, close to maximum yield of oat was obtained at rates of ~3000 gpa of raw liquid swine manure and biodigestate. As in previous years, there appeared to be little difference in the agronomic performance of biodigestate from manure biogas production versus raw liquid swine manure when

considered on a per kg of nutrient added basis. At the long-term liquid swine manure trial, the barley yield was maximized at the 4X annual rate, reflecting good growing conditions and high yield potential at the site. Consistent with results of previous years there was no response to addition of supplemental P fertilizer on the swine manure plots, and no response to addition of nitrification inhibitor. Treatments with skipped applications of nutrient the two previous years did not yield as high when manure was added in 2009. It appears that rates of addition of approximately 100 -150 kg liquid manure N/ha (~ 3000-5000 gallons per acre per year) will maximize production over time in these soils without creating issues of nutrient loading. The results at Melfort long-term swine trial support this, as near maximum yield was observed at these rates. Application at double 1X rate every second year (6000 - 10000 gpa every second year) did not result in as high an oat yield in the second year 2009, pointing towards lower efficiency of total nutrient recovery in the "double up" approach. Some benefit was observed from the commercial S fertilizer application treatment made in 2008. In the 2009 oat crop it showed up in the urea treatments and also in the high rate liquid manure treatment and only for the elemental S form. Generally it appears that some benefit may be observed from fertilization with supplemental fertilizer S on liquid swine manured soils, but the variability in effects regarding crop, form and rates in which benefits are observed makes the benefits difficult to predict. In the long-term cattle manure trials, significant yield responses to manure application were observed as in the previous years, with highest barley yields noted in the highest rate 4X (13 tons dry manure / acre, ~300 kg N/ha) treatment. Repeated application every year at the 2X and 4X rates appears to be necessary to maximize yield owing to lower N availability in solid cattle versus liquid swine manure. However these rates are also associated with P loading of the surface soil. Therefore it is recommended to apply cattle manure at a lower rate such as 1X and meet the rest of the N requirement with urea.

The grain and straw samples were analyzed for nutrient content. Grain N concentrations increased with increasing rate of manure application. Addition of a nitrification inhibitor did not significantly improve apparent N recovery by the crops over the three years, but the broadcast and incorporation application method had significantly lower grain and straw N concentration consistently over the three years, reflecting lower availability of N from liquid swine manure when broadcast and incorporated compared to injected. There was no apparent differences in plant N and P concentrations between biodigestate and raw liquid swine manure, indicating similar recovery of nutrient by the plant from the two different forms. Generally, grain and straw N and P concentrations were less affected by manure or urea applications in 2008 than in 2007 reflecting generally better growing conditions and subsequent growth dilution. Grain and straw P concentrations tended to increase more with cattle manure application than swine manure, reflecting a greater amount of added P as cattle manure. However, this trend was not observed in 2009. Delayed incorporation of cattle manure for 24 hours after spreading did not significantly impact grain or straw N concentration, reflecting the low content of soluble ammonium and low potential for volatile ammonia nitrogen losses with the cattle manure. Impacts of supplemental S fertilizer added to the Melfort sulfur deficient site showed increases in grain and straw S concentration from addition of S fertilizer. Very low grain and straw S content in urea only treatments is consistent with N induced S deficiency being an issue at this site. However, it appears that the liquid swine manure is capable of supplying some additional plant available S, as straw S concentration is increased by addition of liquid swine manure.

Generally, available N levels in the soil in the fall after harvest increased with increasing rate of liquid swine manure. Salinity was not significantly affected except at the 4X (13,200 gpa) annual application

rate at the Dixon long-term site where, for example in 2008, it was elevated to 2.2 mS/cm, and in 2009 it was elevated to 1.3 mS/cm. Repeated application of liquid swine manure at these high rates may create potential salinity concerns for crop growth, and also resulted in greatly elevated nitrate (>200 kg /ha) in the 0-30cm and 30-60cm depths, as did the 4X rate of urea. The content of nitrate in the 60-90cm and 90-120 cm depths was assessed in the Dixon long-term site in the fall of 2009 and revealed that only the 4X annual application of swine manure and urea had elevated concentrations of nitrate at these depths, with 60-100 kg NO3-N present in each depth increment compared to less than 10 kg/ha for the rest of the treatments. Evidence of deep migration of nitrate in the 4X annual applications of liquid swine manure and urea for 13 years indicates that this rate and annual frequency would pose risk to ground water quality. The 1X liquid swine manure rate (~3000-4000 gpa) does not result in soil nitrate or phosphate loading. The high rates of N added were associated with a pH decrease due to nitrification of added ammonium. Accumulation of soil extractable P was not evident in either the raw liquid hog manure treatments or the biodigestate. Reflecting the low P content of the liquid swine manure source used at the long-term site, soil extractable P levels were relatively unaffected by liquid manure application. The inhibitor treatment that was applied with the liquid hog manure had significantly lower nitrate and higher ammonium content, indicating that the inhibitor is doing its job in keeping N in the ammonium form, but did not have a significant effect on the total amount of residual inorganic N. The broadcast and incorporation treatment at Dixon had significantly lower nitrate than injected, again supporting that along with lower crop N recovery, N losses from the system are greater with broadcast and incorporate versus injection. For soil nitrate content in cattle manure treatments, there appears to be limited issues with soil nitrate after ten years except at the 4X annual application rate. Instead the greatest effects of cattle manure addition show up in soil extractable P and K. All cattle manure treatments applied every year have significantly elevated soil test P, with even the 1X rate (~4 tons/acre dry manure) producing nearly 100 kg P/ha in the 0-30cm depth. As measured in 2008, the 4X annual application rate has >250 kg of soil test extractable P/ha in the 0-30cm depth. Periodic rather than annual addition of cattle manure produces less loading. Less frequent and lower application rates are required to avoid P loading with cattle manure, such as 1X every year, 2X-0, or 4X-0-0.

Surface soil cores were also collected in the fall of 2008 after harvest and before fall application of manure for a controlled environment study of microbial carbon dioxide and nitrous oxide production, nutrient release rates, and soil structural characteristics. The objective of this experiment was to assess what effect long-term and short-term swine and cattle manure application had on production of nitrous oxide and carbon dioxide in intact soil removed from the Dixon short and long-term manure and Melfort long-term manure application plots. Soil nitrogen and phosphorus nutrient supply rate and soil physical properties including organic carbon, sodium adsorption ratio and soil strength were also assessed at the end of a ten day incubation period.

All three sites produced limited amounts of nitrous oxide gas over the ten day incubation period, except for a small spike in nitrous oxide production for the Dixon short-term cattle manure and Dixon long-term urea fertilizer at the end of the 10 day incubation period. At the Dixon long-term site, nitrous oxide production values ranged from 4.0 ug N_20 per square centimeter of soil surface per hour in the broadcast and incorporated cattle manure treatment to 18 ug N_20 per square centimeter of soil surface per hour in the urea fertilizer treatment. There was little difference between nitrous oxide production in the short-term versus the long-term manured sites, suggesting that long-term repeated manure application does not increase the potential for nitrous oxide emissions, as long as nitrate is not

allowed to accumulate. Nitrous oxide emissions tended to be greater from urea fertilized treatments than manured treatments. For all three sites, carbon dioxide evolution increased between the first 48 and 96 hours of incubation and then remained relatively stable for the remainder of the incubation period. Manured and urea fertilized treatments tended to have higher carbon dioxide production than unfertilized, unmanured control treatments in some but not all comparisons, but the effects were often not significant.

Soil phosphorus supply was found to be the greatest in the cattle manure treatments. This is consistent with observations made in the field for soil extractable P as influenced by cattle manure addition. Solid cattle manure adds more soluble phosphorus compared to liquid swine manure. Long-term annual applications of liquid swine manure produced greater soil nitrate-nitrogen supply compared to the cattle manure treatments. Liquid swine manure contains more inorganic nitrogen which is readily plant available, unlike solid cattle manure which contains more organic nitrogen and requires more time for microbial decomposition and conversion to inorganic plant available forms of nitrogen.

The application of swine and cattle manure either on a long-term or short-term basis did not affect soil organic carbon or soil sodicity values to any great extent, but there was a trend to higher organic carbon corresponding with manure application. A long period of animal manure application seems necessary to produce significant increases in soil organic carbon in these soils. Manure application tended to increase soil strength slightly but not significantly in the long-term manure trials.

Overall, short and long-term application of fresh and processed swine and cattle manure at agronomic rates of nutrient that balance crop removal over time contribute to significant yield and protein benefits in the crop while minimizing nutrient loading and risk of escape to soils and water.

1. Study Objectives

2007-2009 Field Studies: Crop and Soil Response to Manure Amendment

To determine how short-term (3 yrs) repeated applications of raw liquid swine manure and manure processing by-products from biogas production (biodigestate), and long-term (10yrs +) application of liquid swine manure and cattle manure at different rates, sequences and methods of application influence nutrients, organic matter, soil chemical and physical conditions, crop yield and nutrient content at two manure research sites: Dixon (Black Chernozem) and Melfort (Black Chernozem-Gray Luvisol).

Greenhouse Gas, Nutrient Supply Rate and Physical Properties Incubation

To determine under controlled conditions, how manure management impacts the evolution of the greenhouse gases nitrous oxide and carbon dioxide, as revealed in laboratory incubated intact surface soil cores obtained at the end of the 2008 growing season from the agronomic field trial plots. The end - of - growing season soil nutrient supply rates of ammonium, nitrate and phosphate under incubated conditions are measured simultaneously, and the effect of manure management practices on soil physical properties including soil organic carbon, sodicity and soil strength are evaluated.

2. Materials and Methods

General Experimental Background

The short-term (ST) biodigestate from Biogas production versus raw liquid swine manure comparison experiment, and long-term (LT) liquid swine manure (LHM) and solid cattle manure (SCM) application studies are located in east-central Saskatchewan at Dixon. Another LT liquid swine manure experiment is located in northeast Saskatchewan at Melfort. A short-term cattle manure experiment (broadcast versus injected) (SCM Injected) at Dixon was also used for the lab incubation study. At both the Dixon LT site and Melfort site, treatments of repeated applications of various rates of LHM were applied (SEE APPENDIX C FIELD PLANS FOR TREATMENTS). Repeated applications of various rates of SCM were applied in a separate experiment at the Dixon LT site. At the Dixon ST Biogas and SCM Injected site, various rates of LHM were applied on the Biogas portion of the field study and SCM was applied at various rates using three different application strategies: broadcast only (SCM spread on soil surface), broadcast and incorporated (SCM spread on soil surface and later incorporated into the soil) and subsurface injected (SCM applied in a band under the soil surface).

Each LHM and SCM field trial was set up as a randomized complete block design. *Detailed plot diagrams and treatments for each experiment are provided in Appendix C. Management and cropping history details for years prior to 2007 can be found in ADF project no 20040375 Maximizing Long Term Benefits From Manure Nutrients Applied to Saskatchewan Soil Final Report.* Treatments were

replicated four times at both the Dixon ST and LT sites (for the SCM and LHM treatments), and four times at Melfort. The Dixon LT site was established in the fall of 1996 when LHM and SCM was first applied to the plots. The Dixon ST Biogas and SCM Injected site was established in the spring of 2007 when LHM and SCM was applied to the plots. The Melfort site was established in the fall of 1999 when LHM was first applied to the plots. The control (no manure or urea fertilizer applied) plots consisted of disturbing the soil with the injector unit of the applicator (Prairie Agricultural Machinery Institute (PAMI) LHM injector truck) without any manure or fertilizer being applied. An undisturbed control (no manure or urea fertilizer applied) was also included. At each site, the lowest rate of LHM and SCM being applied (1X) was approximately equal to 80 - 100 kg total N ha^{-1}, and may be considered an agronomic rate in line with the amount of N that would be recommended as fertilizer manure to meet a crop N requirement. Higher rates of LHM and SCM (2X, 4X) were considered to be double and quadruple the recommended agronomic rates of N fertilizer application for an application made every year. Commercial fertilizer consisting of urea (46-0-0) was applied in separate plots at each site for comparison to the results obtained in the manured plots.

Site Description

Dixon Field Sites

The Dixon LT site experiments were initiated in the fall of 1996 on the western half of a farm field (legal location NW 21-37-23-W2) owned by Mr. Collin Ford. The Dixon ST Biogas and SCM Injected site experiments were initiated in the spring of 2007 on the southeastern half of the same farm field. This field is located approximately 6.5 km west of the town of Humboldt adjacent to Saskatchewan Provincial Highway #5, within the Rural Municipality of Humboldt (Photograph 1). The soil at this site belongs to the Cudworth Association and is a Black Chernozemic soil formed in calcareous, silty, lacustrine parent materials and having a loam surface texture (Table 2.1).

Photograph 1. Portion of the Dixon LT hog and cattle manure site, taken on April 15, 2008 after spring snowmelt.

Table 2.1.Soil associations, texture and years of manure application for the three Saskatchewan sites.

Site	Soil Associatio	Texture	Years of Manure Application†
Dixon LT Hog and Cattle	Cudworth	Loam	13
Dixon ST Biogas and SCM	Cudworth	Loam	13
Melfort	Kamsack	Clay loam	10

† Number of years of manure application up to the 2009 growing season.

Melfort Field Site

The LHM study at Melfort was established in the fall of 1999 after harvest operations were completed. The experiments at this site were initiated on a portion of a farm field (legal location SW 26-44-18-W2) leased by Agriculture and Agrifood Canada (AAFC) and located approximately 3.2 km south and 5.7 km east of the town of Melfort and within the Rural Municipality of Star City (#428) (Photograph 2). The soil at this site belongs to the Kamsack Association and is a Dark Gray Luvisol formed in silty lacustrine materials and having a clay loam surface texture (Table 2.1). Sulfur deficiency is an issue at this site.

Photograph 2: Portion of the Melfort site, taken on August 25, 2008 during fall canola crop sampling.

2007, 2008, 2009 Specific Field Study Details

A randomized complete block field experimental design was set up for the biodigestate comparison experiment in May of 2007 in a farm field near Dixon, SK, adjacent to our solid manure injection experiment. Samples of soil were taken from control plots of the biodigestate (ST Biogas)

experimental site in May of 2007 at Dixon to characterize the soils for basic properties (Table 2.2). There are forty plots with three rates of digestate and liquid hog manure: 1500, 3000 and 6000 gallons per acre. Since the biodigestor had ceased operations at the Cudworth hog barn, it was necessary to manufacture the biodigestate from manure using PAMI's pilot scale biodigestor. Commercial urea fertilizer nitrogen was used for comparison purposes. The Dixon long-term swine manure and cattle manure experimental treatments are the same as in the past 10 years and were applied in the spring (April) of 2007, fall (October) of 2008 and fall of 2009. Dancer oats were seeded at the Dixon site in early June of 2007, Nexera canola in May of 2008, and Stander barley in 2009. The Melfort site received manure applications in the fall of 2006, 2007 and 2008 and had Stander barley seeded in May of 2007, Invigor canola in May of 2008, and Morgan oats in May of 2009. Rates of manure nutrient application made for the 2007, 2008 and 2009 seasons at all sites can be found in Appendix A. Grain and straw yields at maturity were obtained by taking two square meter samples from each plot in late August - early September period at each site. The samples were threshed and grain and straw yields determined by weighing, followed by grinding for nutrient analysis. In the fall after harvest of 2007 and 2008, soil samples (0-30cm, 30-60cm) were taken from each plot and analyzed for available nutrients and soil chemical properties. These same samples and deep samples (60-90cm, 90-120cm) samples were also taken from selected treatments in the fall of 2009 and analyzed for ammonium and nitrate. Harvested grain and straw samples were analyzed for available nutrient content by digestion or combustion. The grain and straw yields, nutrient content, soil nutrients and properties are found in Appendix B. Data was analyzed for significant differences at $p<0.10$ using ANOVA in SAS software, and the LSD was calculated and used for mean separation.

Table 2.2. Basic properties of control plots at Dixon Biodigestate experimental site.

Sample	Plot	Depth cm	Nitrate ug/g	Sulfate ug/g	pH	EC
Controls	2	0-15	11.1	3.4	7.1	0.33
	2	15-30	4.7	4.8	8.0	0.22
	2	30-60	2.3	1.6	8.2	0.42
	14	0-15	8.7	1.6	8.0	0.20
	14	15-30	2.5	3.0	8.1	0.22
	14	30-60	1.2	3.7	8.5	0.26
	26	0-15	6.5	3.9	7.5	0.16
	26	15-30	3.1	6.2	8	0.25
	26	30-60	1.7	7.0	8.0	0.34
	34	0-15	6.2	5.5	7.9	0.18
	34	15-30	2.3	6.5	8.1	0.17
	34	30-60	1.4	5.8	8.3	0.15

Fall 2008 Greenhouse Gas and Nutrient Supply Rate Soil Core Incubation Study

Soil Sampling

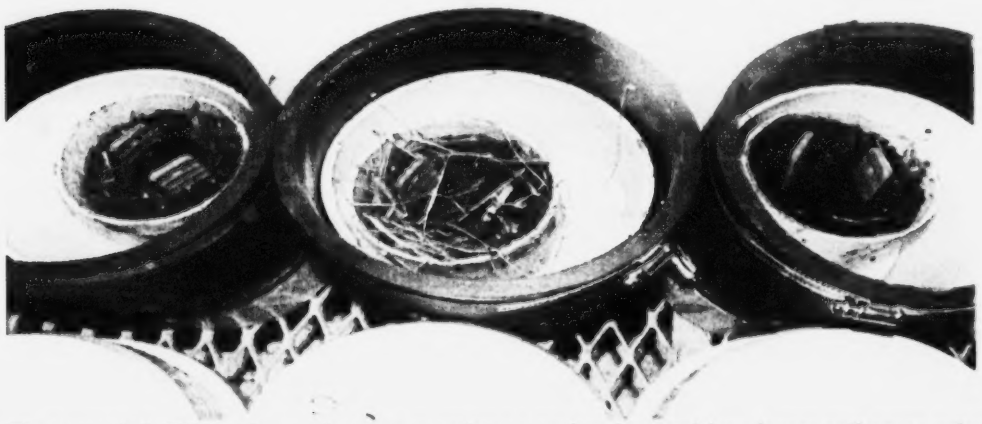
Soil cores for the controlled environment incubation experiment were collected at both the Dixon LT and ST sites and Melfort in October 2008 after harvest and prior to the fall manure and fertilizer applications. Soil samples were taken using polyvinylchloride (PVC) pipes measuring 15 cm in height and 10 cm in diameter. Four PVC cores were inserted per plot. The cores were then removed by

excavation, bagged, labelled, removed from the site and stored at in a refrigerated facility at -20 °C for incubation and processing.

Soil CO_2 and N_2O Gas Measurements

Intact Soil Core Incubation Protocol

The intact soil PVC cores were removed from the refrigerated facility, allowed to thaw for 24 h and wetted to field moisture capacity by adding 150 ml of water to simulate a light rainfall. This is equivalent to 2.5 cm of rainfall. The intact soil cores were allowed to equilibrate for 96 h before the incubation study began. The cores were then placed inside an growth chamber equipped with electronically controlled environmental settings. Chamber conditions were set for 25 °C and illuminated for 16 h, and 18 °C with no light for 8 h. Prior to the commencement of the incubation study one anion and one cation Plant Root Simulator™ (PRS) ion exchange membranes were inserted into each of the intact soil cores to measure nutrient ion supply rates while greenhouse gas CO_2 and N_2O fluxes were being sampled (Photograph 3).



Photograph 3: PRS anion and cation membrane probes inserted into intact soil cores prior to the beginning of the incubation study.

Carbon Dioxide and Nitrous Oxide Gas Sampling

The incubation experiment consisted of the intact soil cores inside the PVC pipe being placed inside a two part PVC container with dimensions of 15 cm diameter and 15 cm in length and being joined together and sealed using a rubber airtight flange fastened with hose clamps (Photograph 4). A rubber septum was inserted into one end of the sealed container to allow gas samples to be extracted using a syringe. A syringe needle (20 cm^3) was inserted carefully through the rubber septum and a chamber air sample was drawn and transferred into an air evacuated 20 cm^3 exetainer. Gas sampling occurred at 48, 96, 144, 192 and 240 h after the incubation experiment commenced. After gas samples were obtained, the sealed PVC chambers were unsealed, the tops removed and natural airflow allowed to move between the growth chamber and the intact soil cores.

Photograph 4: Intact soil cores after gas sampling, opened for aeration.

Carbon dioxide and nitrous oxide concentrations were determined using a Varian Micro-GC CP-2003.

Soil Ammonium, Nitrate-Nitrogen and Phosphorus Supply Rates

Intact soil core bioavailable NH_4-N, NO_3-N and PO_4 soil nutrient supply rates were determined using PRS Probes™. The anion and cation exchange membrane probes were inserted into the intact soil cores just prior to the commencement of the incubation experiment. After the 10 day incubation experiment concluded, the PRS probes were removed, washed, and eluted with HCl which was colorimetrically analyzed for nutrient ions using automated colorimetry.

Soil Physical Properties

After the incubation experiment concluded, soil was removed from the PVC cores, mixed, air-dried, ground to pass a 2-mm sieve and stored in labelled plastic bags at 20 °C for soil physical property analysis of soil organic carbon (SOC), sodium adsorption ratio (SAR), modulus of rupture (MOR) and coefficient of linear extensibility (COLE). Soil was removed from the PVC cores, and the four cores from each plot bulked, mixed, air-dried, ground to pass a 2-mm sieve and stored in labeled plastic bags at 20 °C. The SOC contents of ground soil samples (0-15 cm) of approximately 0.15 g, previously ground with a ball mill to pass a 100-mesh sieve, were measured by the dry combustion method.

To assess sodicity (SAR), five grams of each PVC soil core sample was weighed into plastic containers. Fifty ml of 1 *M* ammonium acetate was added to the containers. The ammonium acetate will displace adsorbed cations off the cation exchange sites in the soil. The containers were sealed and placed for 30 min on a reciprocating shaker. The cations Na, Mg^{2+} and Ca^{2+} were analyzed using a Perkin Elmer Model 3100 atomic absorption spectrometer and the SAR equation used to provide an approximation of SAR. SAR = Na concentration divided by square root of Ca + Mg concentration. Concentration in millimoles (+) per litre of extract.

For modulus of rupture (MOR), the 0-15 cm depth increment of soil was removed from the soil cores and the <2-mm sieved fraction was poured into briquete steel molds using a funnel. Soil was scraped from the top of the mold and the molds were then placed in a plastic bucket. Ordinary tap water was then slowly added. After the wetting, the molds were then placed in an oven at 50 C (Photograph 5). After the briquets were determined to be dry, they were placed on a breaking machine where a constant force was applied to break the briquets in half. The amount of water used to break each briquete was measured and that weight was converted to kPa to determine the strength of each sample. The COLE was determined using the same briquets described in the MOR experiment. Electronic calipers were used to measure the oven dried soil briquets length and width. The wet length was determined by measuring the inside length of the steel molds (70 mm). COLE = length of moist soil – length of dry soil divided by length of dry soil.

Photograph 5. Soil briquets with molds removed after baking in oven.

Statistical Analysis

The experimental design on all field experiments was a randomized complete block design. Statistical comparisons were conducted using least significant difference (LSD) ($p \leq 0.10$) from a standard analysis of variance technique. All LSD calculations were conducted using the general linear model procedure (SAS, 2008).

3. RESULTS and DISCUSSION

3.1 2007,2008, 2009 FIELD STUDIES: CROPS & SOILS

2007

Raw (Unprocessed) Liquid Hog Manure vs Biodigestate Trial, Dixon, SK

2007 Agronomic Results

OAT YIELD

The rates used were 1500, 3000 and 6000 gallons per acre (gpa) and a 70 lbs N / acre urea treatment. The biodigestate has higher N content (~21 lbs N / 1000 gallons) versus Raw LHM @ 14 lbs N / 1000 gallons. Therefore more total N and ammonium N was added at equivalent gallonage rates in the biodigestate plots. As for the P contents and forms, there was little difference between the Raw and Biodigestate.

The site had a moderate available N content of about 28 kg of available N / ha in the 0-60cm depth. There was a significant response of oat yield to manure and urea, with an increase in yield of about 1000 kg / ha over the control. The low rate of liquid manure addition (1500 gpa) or 70 lbs of N / acre as urea was sufficient to maximize oat yield. There was no significant grain yield response to higher rates of application while straw yield increased slightly.

OAT NUTRIENT

The grain N concentration was significantly increased by manure application (both raw and biodigestate), and increased with increasing application rate (Figure 3.1). The N concentration in the grain and straw of the oats from the biodigestate treatments was slightly but not significantly higher than for the raw liquid manure (LHM) at the same gallonage application rates. This likely reflects the greater N content of the biodigestate manure than the raw manure. Overall, the biodigestate appears to have a similar effect on the crop as the raw liquid hog manure at equivalent rates of added nitrogen. The P concentration in the grain and straw was highest in the biodigestate high rate treatment (6000 gpa). There was very little effect of either the raw liquid hog manure or biodigestate on grain or straw P content, consistent with the low P content of this manure. The soil may be considered marginally deficient in P, with ~ 10 µg P / g of modified Kelowna extractable P.

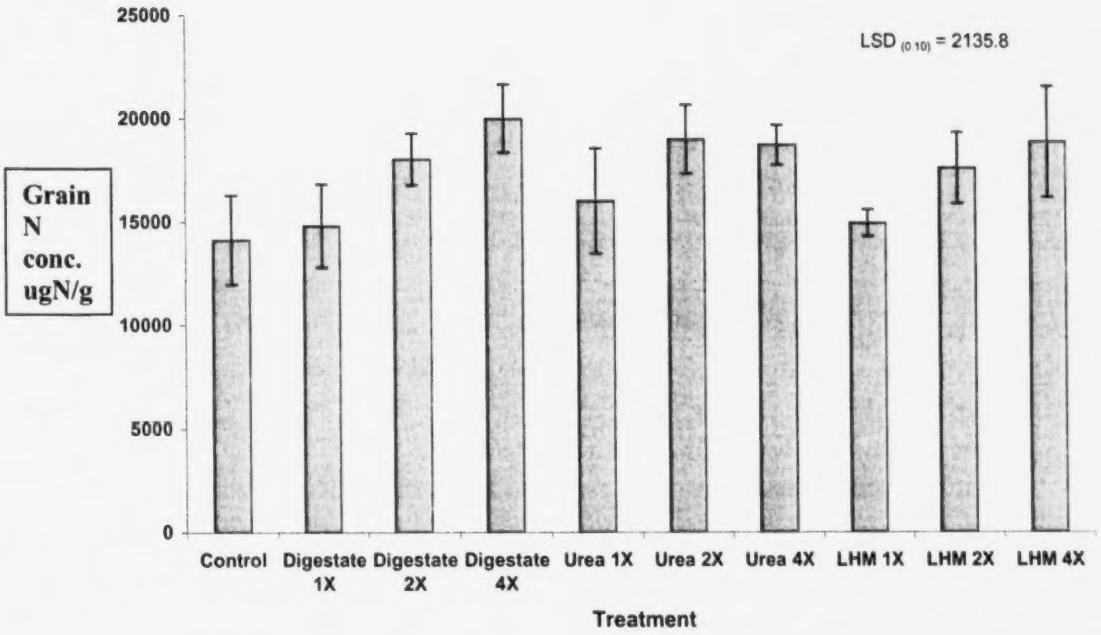


Figure 3.1 Grain N concentration (ug/g) in oat from biodigestate versus raw liquid swine manure (LHM) comparison.

SOIL PROPERTIES IN FALL OF 2007

The soil electrical conductivity (salinity) tended to increase slightly, although only a very small increase of about 0.1 units, from the control to the high rates of all the amendments. The pH was also not greatly affected, but there was a trend downward with the urea 4X treatment having a pH of 6.9 versus 7.3 in the unamended control. This decrease in pH is likely a consequence of nitrification and the associated acidity produced. As expected, since this was the first year of manure addition and it can take many years to have a significant measurable effect, the soil organic carbon concentrations were not significantly affected by the manure or urea additions.

Reflecting the low P content of the raw liquid hog manure and biodigestate of only about 3 to 4 lbs of P per 1000 gallons, the addition of raw and biodigestate had no significant effect on modified Kelowna extractable P (0-15cm depth) in the fall after harvest. In the urea treatment, there was a slight decrease in the soil test P. This is consistent with a balance in the amount of P added in manure versus the amount of P removed by the crop and contrasts with the results of an adjacent research project where cattle manure of an N:P ratio of ~2:1 resulted in significant increases in soil test P after one year of addition. There was a trend for the modified Kelowna extractable K in the 0-15 cm depth to be decreased as well for the raw, biodigestate, and urea treatments, perhaps as a result of the low K content of the manure (only about 5-6 lbs K / 1000 gallons). As expected, there was no significant effect on P and K in the 15cm – 30cm layer.

There was no significant difference in residual soil nitrate among rates for the digestate in the 0-15 cm depth, except that the high rate (6000 gpa) was elevated. The middle and high rate of urea addition (100 and 200 lbs N / acre) also produced soil residual nitrate levels in the fall that were elevated over the control and 50 lbs N / acre treatment. The raw LHM increased soil nitrate at the high rate, but not as much as the digestate. The raw manure has a lower N content. There were no significant effects at the 15-30 cm and 30-60 cm depth increments except for the high rate of urea.

Long-Term Liquid Swine Manure Trial, Dixon, SK

2007 Agronomic Results

OAT YIELD

The 2007 season represents the 11th year of the study. The liquid hog manure (LHM) significantly increased oat grain and straw yield over the unfertilized control, with a grain yield of 3300 kg/ha on the control vs 5300 kg/ha on the LHM treatment (Figure 3.2). The highest yield was observed on the 1X annual application rate (~ 80 lb N/acre) and the 4X every three years, with 2007 being the second year after the 4X application. On both the first year of application in the biodigestate vs raw manure study, and in this long-term repeated application rate study, yield was maximized in the 1X treatment, that based on previous results is also considered to be the optimum annual application rate. Carryover and a positive yield effect was observed from the 1X and 2X treatment applied in 2006 but not in 2007. The oat grain yields in the 2X rate (6600 gpa) every year and 4X rate (13,200 gpa) every year were significantly lower than the 1X (3300 gpa) every year.

The broadcast and incorporation treatment had significantly lower yield than the injected treatment, showing for the eleventh consecutive year that injection is an agronomically superior application method. As in 2005 and 2006, the nitrification/urease inhibitor (Super N) additive had no significant effect on yield. The water only treatment yielded the same as the controls. The 1X urea treatment had significantly lower yield than the LHM 1X treatment, reflecting the fact that ten years of addition of only nitrogen has drawn down and created deficiencies of other nutrients. However, the addition of supplemental P fertilizer had no significant impact on yield of the LHM treated plots or the urea plots. In previous years, crop response to P fertilizer addition on the urea plots has been observed. Lack of response to P fertilization may be a result of the crop grown (oats) which is not a high nutrient user, and the late seeding date of June 14 that would limit the starter or pop-up effect from the applied P.

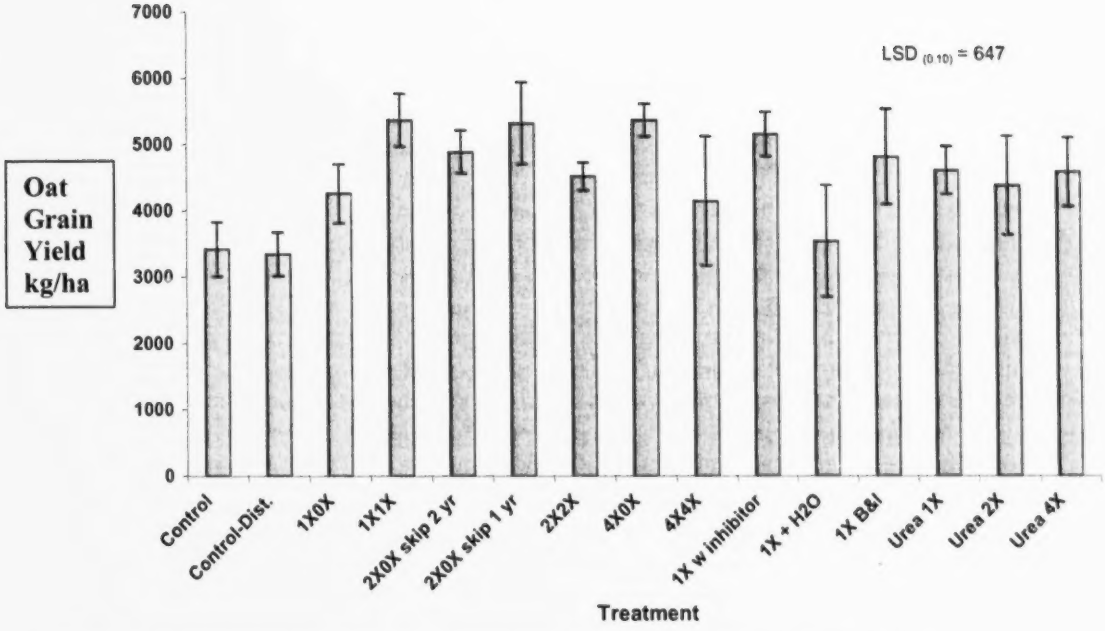


Figure 3.2. Oat grain yield at Dixon long-term liquid swine manure trial in 2007.

OAT NUTRIENT

Oat grain and straw N was significantly increased by addition of liquid hog manure and urea, as expected. There was no significant difference in grain N and straw N in the nitrification/urease inhibitor treatment compared to the no-inhibitor treatment. Again, in 2007, as in 2006, the inhibitor did not seem to have a significant effect on improving crop yield or N recovery. The broadcast and incorporation treatment for swine manure had a much lower grain and straw N concentration than the injected treatment. Overall, the broadcast and incorporation application appears to result in lower crop N recovery and greater N loss compared to band injected. The grain and straw P concentrations were not greatly affected by manure addition, with similar P concentrations or a slight increase at the high rate of manure addition. As anticipated, grain and straw P concentrations were significantly lower in the urea treatment than in the manured treatment.

SOIL PROPERTIES IN THE FALL OF 2007

The soil pH was lower in the liquid swine manure and commercial fertilizer urea plots, as noted in previous years. This drop in pH is associated with acidity produced from conversion of ammonium to nitrate (nitrification process). The electrical conductivity was increased with manure and urea application from 0.3 to 0.8 mS/cm at the 4X annual application (highest total amount of

manure applied of all treatments). Overall there appears to still be no major issue with build-up of salts associated with long term manure application at this site.

As in previous years, the 4X annual application treatment is leading to accumulation of large amounts of nitrate in the 0-30cm and 30-60cm depths. There is little influence on ammonium, indicating that the ammonium added in the liquid swine manure is rapidly nitrified to nitrate. The 1X manure treatment has higher fall nitrate levels than the control, indicating that the oats did not use all the nitrogen. The soil nitrates in the 1X-0X, 2X-0X and 4X-0X (second year after application) treatments are all low and similar to the control. It is noteworthy that the 1X treatment with inhibitor has significantly lower nitrate and higher ammonium content than the treatment without the nitrification inhibitor. This indicates that the inhibitor (applied in the spring with the liquid hog manure) has kept N in the ammonium form and its effects are still evident in the fall. This trend is also evident at depth. The total amount of inorganic N (ammonium + nitrate) is not much different with or without the inhibitor, and also there is not much effect on N in the crop. Therefore the inhibitor does not appear to have had much effect on reducing N losses over the growing season, but less profile nitrate could mean less loss in the winter period. The 1X broadcast and incorporation treatment has significantly lower soil nitrate than the injected treatment, again supporting along with lower crop N recovery, that N losses from the system are greater with broadcast and incorporate versus injected swine manure. Interestingly, this does not appear to the be the case so far with solid cattle manure, as injection versus broadcast and incorporate has resulted in little yield or N recovery differences.

Swine manure addition has increased the extractable P level above the unfertilized control (~ 20 kg modified Kelowna extractable P/ha in 0X) to about 40 kg extractable P in the 4X annual application treatment. The extractable P levels are lowest (lower than control) in the urea treatments and also in the broadcast and incorporation treatment. Additional P losses may be occurring in the B and I liquid swine manure treatment since crop removal is less because of lower yield and yet same amount of P as 1X rate is added. Extractable K is increased with manure addition, as observed in other years. The lowest extractable K is found in the urea treatments.

Long-Term Solid Cattle Manure Trial, Dixon, SK

2007 Agronomic Results

OAT YIELD

Like the liquid swine manure trial, this trial with solid cattle manure has been in place for eleven years. The oat yield of the control plots was relatively high at this site this year compared to other years. This likely reflects the low fertility requirement of oats compared to some of the other crops grown. The highest yield was observed in the 2X annual application rate treatment. The 2007 carryover effects from applications made in the 2006 season increased from 1X-0X to 2X-0X to 4X-0X treatments. The 4X annual application rate treatment was not a very good yielder, as it yielded similar to control. It appears that the 2X annual application rate (7 tons dry manure/acre/yr) treatment is the best. There was no difference in grain yield between broadcast and incorporated immediately versus 24 hr delayed incorporation, similar to previous years and is consistent with our other studies that have shown relatively little impact of solid cattle manure placement on yield or N recovery.

OAT NUTRIENT

Addition of cattle manure and urea significantly increased grain N (protein) and straw N concentration over the control, reflecting increased N availability, and concentration in grain and straw increased with increasing rate of addition. The crop recovery of N appears similar between broadcast and immediate incorporation versus 24 hour delayed incorporation. The grain and straw P concentrations increased with increasing rate of manure application as expected. The urea treatment had the lowest P concentration in grain, and especially in the straw, similar to urea treatments in the long-term swine manure trial.

SOIL PROPERTIES IN THE FALL OF 2007

The addition of cattle manure had no effect on soil pH while soil with the high rate of urea (200 lb N/acre) over the last ten years had significantly lower pH than the control or cattle manure treatments, presumably due to the acidity produced from nitrification. The manure and urea treatments had some slightly elevated E.C. values, but were generally less than 0.5 mS/cm.

The application of cattle manure every year resulted in significantly higher soil nitrate content in the 0-30cm depth compared to the control, and the levels tended to increase with rate. The highest soil nitrate of 90 kg NO_3-N/ha in the 0-30cm depth was observed in the 4X treatment (~14 tonnes dry manure / acre) applied every year. The alternating year treatments had nitrates that were slightly elevated over the control treatments. Only the 4X annual application showed elevation at the 30 – 60 cm depth. Overall, it appears that the cattle manure is not causing soil nitrate loading problems after eleven years, except at the 4X annual application rate.

The greatest effects of the cattle manure addition appear in the soil extractable P and K. All the treatments applied every year have significantly elevated modified Kelowna extractable P. Even the 1X annual application rate is approaching 100 kg P/ha 0-30cm depth and the 4X annual application is > 200 kg MK extractable P, while 2X annual is 122 kg MK extractable P/ha. Potassium loading is also apparent with about 3000 kg MK extractable K/ ha in the 4X annual application treatment versus 1000 kg MK extractable K / ha in the control. Periodic rather than annual addition of cattle manure produces less loading.

Long-Term Liquid Swine Manure Trial, MELFORT, SK

2007 Agronomic Results

BARLEY YIELD

There was a very large yield response of barley to liquid swine manure addition at the Melfort site in 2007 (Figure 3.3). The 2007 season is the eighth year of the trial. The 1X (3300 gpa) annual application treatment produced the highest yield: ~4500 kg /ha versus the control barley grain yield of

~1500 kg/ha. Some carryover benefit of the 2X and 3X applications made in 2006 but not in 2007 were evident in the 600-800 kg /ha additional grain yield produced in these treatments compared to the control. The addition of sulfur fertilizer in 2005 had a large impact on barley yield in 2007, especially in the urea treatment where barley yield was increased by 1.5X by S addition (Figure 3.3). A significant yield benefit of supplemental S fertilizer was also sometimes observed in the manure treatments but was less than for urea. There was no difference between elemental and sulfate S sources in the annual 1X and urea treatments, but the sulfate source appeared to perform better in the 2X-0X and 3X-0X treatments. The reason for this is not known.

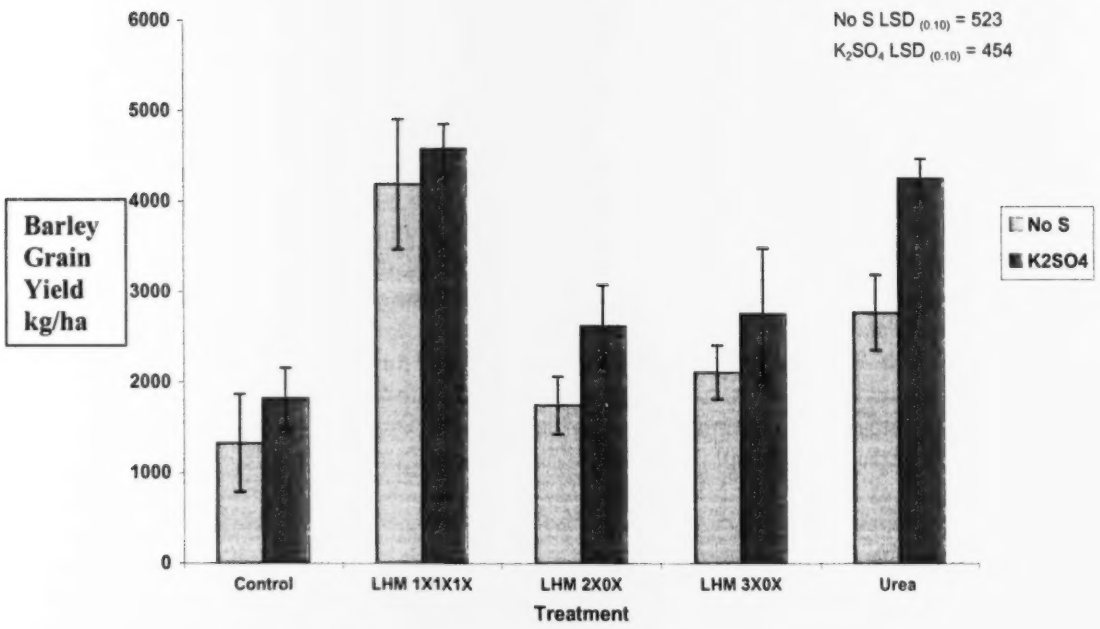


Figure 3.3. Barley grain yield at Melfort site in 2007.

BARLEY NUTRIENT

The addition of liquid hog manure increased the grain and straw N concentration in the barley but not hugely. The manure addition tended to decrease grain and straw P concentration, similar to urea. Again, this likely reflects a low addition of P from swine manure. This is consistent with the soil extractable P level which was reduced in the manure and urea treatments. The S concentration in the grain was increased with the S fertilizer application made in 2005, indicating that there is residual S that is contributing to availability in the 2007 season. The grain S concentrations were highest in the sulfate S treatments, higher than for elemental S, likely as a result of greater S availability in the

sulfate S fertilizer form treatments. Application of swine manure and urea reduced the S content of the grain due to dilution effects.

SOIL PROPERTIES IN THE FALL OF 2007

The soil pH was not significantly affected by manure, urea or S fertilizer amendment. The E.C. (salinity) values were very low, reflecting the highly leached nature of this site, and were not significantly affected by treatment.

The soil nitrate amounts were low in all treatments, with some small elevation in the 1X annual application and the 2X-0X and 3X-0X over the control in the treatments without S fertilizer amendment. In the treatments with S fertilizer amendment, soil nitrate levels were all very similar to the control, suggesting that S fertilizer may be increasing crop utilization of soil N and thereby reducing soil nitrate content. There was no impact on ammonium levels. Overall, there appears to be no issue with nitrate loading at this site with any of the treatments.

The modified Kelowna extractable soil P was lower than the control in the manure and urea fertilized treatments, with and without added S fertilizer. It appears that P loading is not an issue at this site. Rather, instead it may be P depletion. According to the analysis of the manure applied in fall of 2006 for the 2007 season, the total N: total P ratio of the manure is around 5. However, the content of soluble P in the manure is much lower. The modified Kelowna extractable K did increase with manure addition, and was lowest in the urea treatment.

2008

Raw (Unprocessed) Liquid Hog Manure vs Biodigestate Trial, Dixon, SK

2008 Agronomic Results

CANOLA YIELD

At this experimental site in 2008, there was more variability in yield than normal due to patchy germination in spring and subsequent weed pressure as a result of difficulties in seeding into the oat crop residue from the previous year. The highest canola grain yields were found in the 1X biodigestate treatment. Overall, as in 2007 there appears to be little difference in agronomic performance of the raw liquid swine manure and the biodigestate. At equivalent rates of product added, the biodigestate added slightly more ammonium N but slightly less total N, total P and soluble P. Yield tended to be lower in the urea treatments than the manure treatments, and declined with increasing rate. Some limitation like P or S may be responsible for lower yields in the urea treatments.

CANOLA NUTRIENT

Canola grain and straw N and P concentrations were not greatly affected by manure or urea applications in 2008. Unlike 2007 with oats, in 2008 with canola there was a trend to lower concentrations of N in the low rate of raw manure or biodigestate compared to the control, likely due

to growth dilution. Higher rates produced similar N concentrations. There was no significant difference in plant N or P between biodigestate and raw liquid hog manure at the same rate of application, indicating similar agronomic effects as observed in 2007. Lower canola yields with increasing rate of added urea may reflect some N induced S deficiency, as there was no evidence that N or P was becoming limiting.

SOIL PROPERTIES IN FALL OF 2008

In 2008, the soil pH was reduced by application of raw manure, biodigestate or urea. The same trend was observed in 2007. The pH reductions range from 7.8 in the control to about 7.1 in the high rate of application treatments. This indicates that nitrification of the added ammonium is the likely cause of the acidification observed. Soil salinity was not significantly affected. As in 2007, the soil organic carbon content (0-15cm) was not significantly affected, since 2008 represents the effects of only two years of manure applications made.

The soil nitrate in the 0-15cm depth increased significantly with increasing rate from about 6 kg / ha in the control to 13 kg nitrate-N / ha in the high urea and digestate rates, and to 33 kg / ha in the high rate of raw manure. In 2007, the biodigestate increased soil nitrate more than the raw manure. Although the biodigestate added slightly more ammonium, it did add slightly less total N and P according to manure analysis. However, the biodigestate produced a small but significant increase in residual soil P and K while the raw manure did not. The only nutrient effect at depth (15-30 and 30-60 cm) was a significant elevation in nitrate for the raw manure 4X (6000 gpa) rate over all the other treatments for both depths. Other treatments and nutrients were low and not significantly different from the control. The 6000 gpa treatment likely supplied too much available N relative to crop requirement that resulted in some of the excess nitrate moving downward.

Long-Term Liquid Swine Manure Trial, Dixon, SK

2008 Agronomic Results

CANOLA YIELD

In 2008, there was a strong yield response to the manure applications made in the fall of 2007. The annual applications at 1X (~80 lbs N/acre), 2X and 4X rates produced the highest canola grain and straw yields (Figure 3.4). A residual effect of applications made in 2006 but not in 2007 or 2008 was noted in the 2X-0-0 treatment and 4X-0-0 treatments, but not in the 1X-0-0 treatment. Addition of the nitrification inhibitor Super N had no beneficial effect, and mean grain yield was actually lower. As in all previous years starting in 1997, the broadcast and incorporation treatment yielded less than the injected treatment. The 1X rate injected every year performs well. The urea treatments did not yield well, likely due to P deficiency, as evidenced by significant increases in the yield of urea amended plots with P fertilizer addition (Figure 3.4).

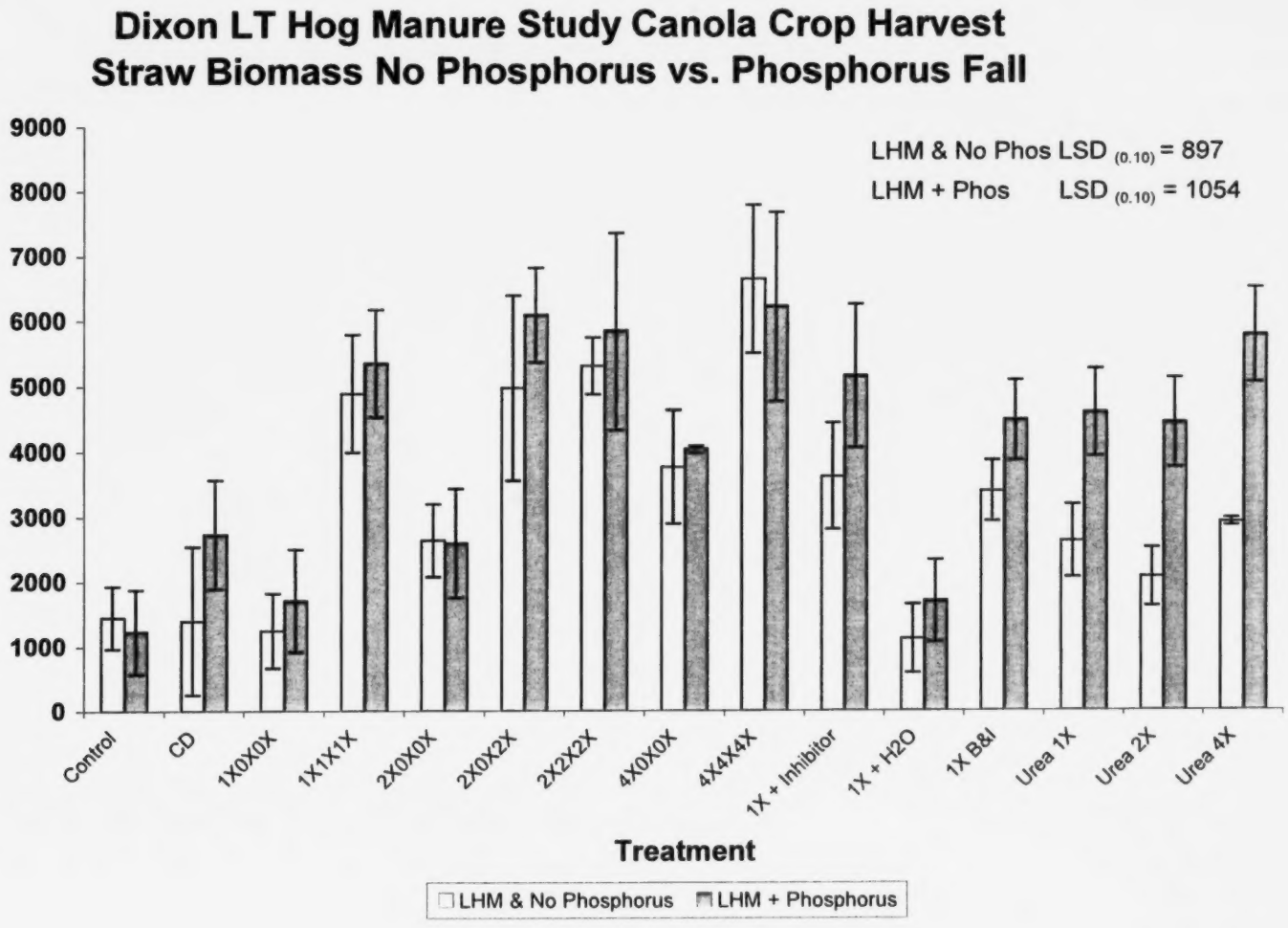

Dixon LT Hog Manure Study Canola Crop Harvest
Straw Biomass No Phosphorus vs. Phosphorus Fall
LHM & No Phos LSD (0.10) = 897
LHM + Phos LSD (0.10) = 1054
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Control
CD
1X0X0X
1X1X1X
2X0X0X
2X0X2X
2X2X2X
4X0X0X
4X4X4X
1X + Inhibitor
1X + H2O
1X B&I
Urea 1X
Urea 2X
Urea 4X
Treatment
LHM & No Phosphorus
LHM + Phosphorus

Fig 3.4

There was a large response of the urea treatments to the addition of phosphorus fertilizer. Interestingly, a yield response to P was seen in the inhibitor and broadcast + incorporation treatments. It is possible that P from manure is stranded at the surface in the broadcast + incorporated treatment. Support for this concept is found in the 2009 results at this site as well. As expected, there was no signficant response to supplemental P in the 1X, 2X and 4X annual applications of swine manure, indicating that the swine manure was supplying sufficient P.

CANOLA NUTRIENT

Effects of the long-term liquid swine manure applications on grain and straw nutrient concentration in canola in 2008 were very similar to effect on oat grain and straw in 2007 and other crops in previous years. Canola grain N concentration and therefore protein, and especially straw N concentration, increased significantly with application of liquid swine manure and effects were greatest with annual applications, although the effects of application made at 2X and 4X rates two years earlier could still be seen in elevated N concentration (protein) in grain. Effects on grain and straw P were muted, with lower P than control observed in 1X and 2X liquid swine manure treatments. This is consistent with the low P content of this liquid swine manure source that results in relatively little addition of P compared to N, and a P deficit at lower rates. There was no significant difference in grain N or straw N concentration between the nitrification inhibitor and no inhibitor 1X treatments. This indicates that as in past years, the addition of the nitrification inhibitor to the liquid swine manure did not have a significant effect on N availability and recovery by the canola crop. Grain and straw N concentration and biomass yield were significantly higher in injected liquid swine manure versus broadcast and incorporated liquid swine manure treatment. This is in agreement with results from all previous years and is a reflection of greater crop N recovery with injected bands versus surface broadcast and incorporate application of this manure type. Grain and straw P concentrations were similar between placement treatments.

As in past years, urea had lower P grain concentration than manure treatments, reflecting no P addition. The addition of supplemental P fertilizer significantly increased the P concentration in the grain and straw of the canola as expected. Some of the largest increases were in the nitrification inhibitor, broadcast and incorporation placement, and urea treatments. These were treatments where there were also significant yield increases associated with P fertilizer addition.

SOIL PROPERTIES IN THE FALL OF 2008

The effects on soil pH (0-30cm) were small, but with a trend towards lower pH with manure or urea application compared to the control. The soil pH was lower in the liquid swine manure and commercial fertilizer urea plots than the control, as noted in previous years. This drop in pH is associated with acidity produced from conversion of ammonium to nitrate (nitrification process). There is less effect on pH noted in the long-term liquid swine manure trial than the short-term biodigestate - raw manure trial, likely due the greater sampling depth used in the long-term swine manure trial site (0-30 cm vs 0-15 cm). A greater sampling depth will cause dilution and include some subsoil carbonates that would buffer any pH effects taking place in a localized zone close to the surface. As in 2007, the electrical conductivity was significantly elevated in the 4X annual repeated application of manure or urea. In 2007, the electrical conductivity was increased with manure and urea application from 0.3 to 0.8 mS/cm at the 4X annual application. In 2008, the 4X annual swine

manure application had an EC of 2.2 mS/cm. Overall there appears to be no issue with build-up of salts when manure application is made over the long-term at agronomic (1X) or 2X rates at this site, but excessive 4X annual rates appear to lead to high electrical conductivity, and potential salinity concerns for crop growth.

As expected from previous years results, the 4X annual application treatment resulted in greatly elevated nitrate (> 200 kg /ha) in the 0-30cm and 30-60cm depths, as did the 4X urea (Figure 3.5) Reduced frequency and rate resulted in much lower fall residual soil nitrate levels. Also as anticipated, given the relatively low addition rate of total and soluble P with the liquid swine manure, soil extractable P levels were relatively unaffected by any of the liquid manure rates, with only slight elevation at the 4X annual rate. Urea treatments as in 2007, had the lowest residual soil P content. As in other years, the liquid swine manure is observed to result in significant increases in extractable, exchangeable soil K.

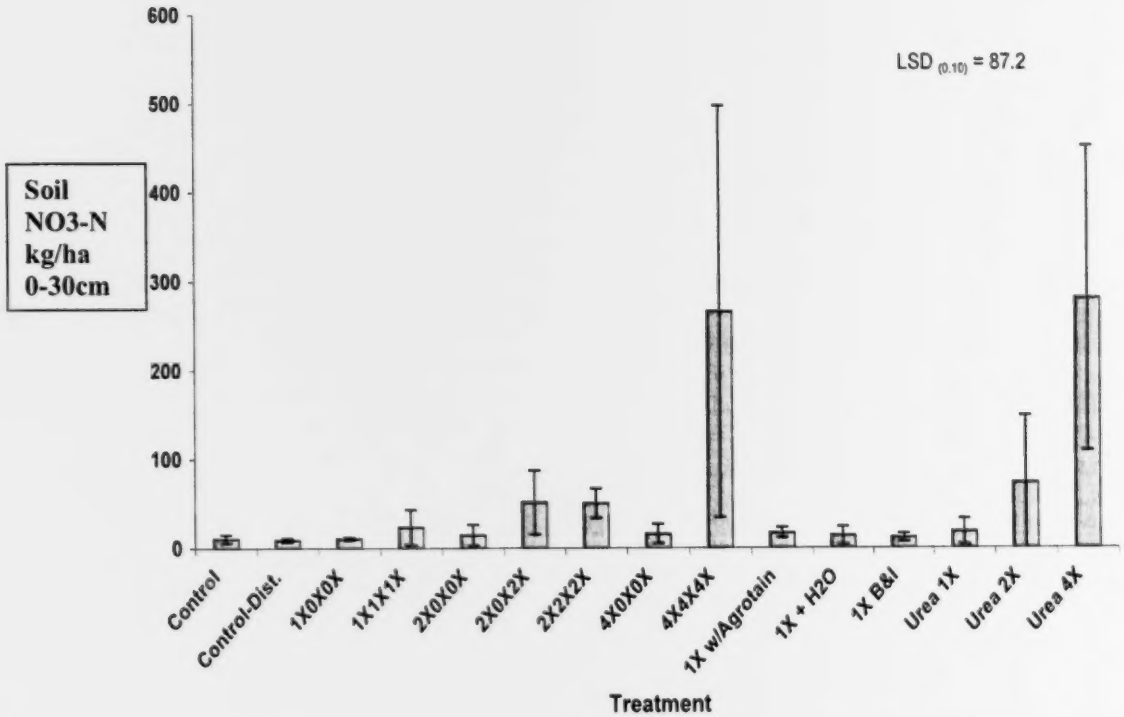


Figure 3.5. Soil extractable NO_3-N (0-30cm) fall 2008 at Dixon LT liquid swine manure trial.

Long-Term Solid Cattle Manure Trial, Dixon, SK

2008 Agronomic Results

CANOLA YIELD

There was a sizable yield response of the canola to the addition of cattle manure (Figure 3.6), although yields were not quite as high as in the swine manure study. As in previous years, the highest yields were obtained in the annual application rate treatments, especially the 4X (~14 tons dry manure/acre). The 4X-0-0 and 2X-0-0 treatments did not yield as well as the annual treatments. There was no significant difference between the broadcast and immediate versus 24 hour delayed incorporation, similar to the findings of other years. Similar yields of the urea treatments to cattle manure suggest a possible P limitation in the urea treatment and an available N limitation in the cattle manure treatments. The straw biomass followed a similar pattern to grain yield.

CANOLA NUTRIENT

Both grain and straw N and P concentrations responded positively to annual cattle manure addition, with the highest concentration of P observed at the 4X annual application rate. Greater effects on plant P than N in the long term cattle manure trials versus greater effects on plant N than P in the swine manure trials reflects the greater amount of P added to the soil as cattle manure compared to liquid swine manure per unit of N, as covered in the previous section. Lower frequency of addition i.e. 4X-0-0 did not produce increased grain N concentration and only small increases in grain P concentration. Urea treatments had grain P concentrations that were much lower than manure treatments, reflecting P depletion by adding only urea. As in previous years, delayed incorporation of the cattle manure did not significantly affect grain or straw N concentration or yield, indicating that a delay in incorporation does not significantly reduce N availability or recovery versus immediate incorporation with this type of manure. The cattle manure used in this study has a low content of soluble ammonium and therefore low potential for volatile nitrogen losses.

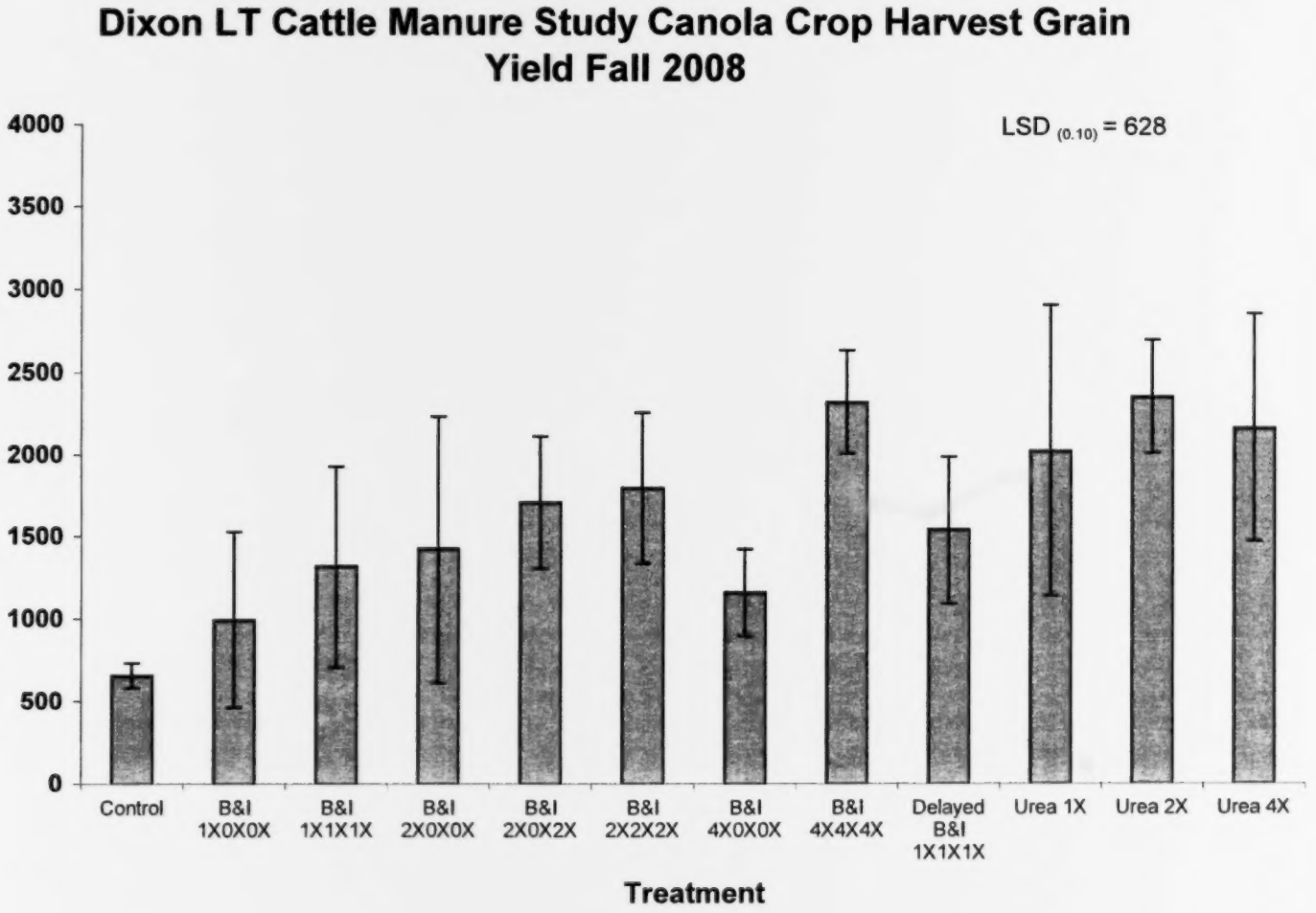

Dixon LT Cattle Manure Study Canola Crop Harvest Grain Yield Fall 2008
LSD (0.10) = 628
4000
3500
3000
2500
2000
1500
1000
500
0
Control
B&I 1X0X0X
B&I 1X1X1X
B&I 2X0X0X
B&I 2X0X2X
B&I 2X2X2X
B&I 4X0X0X
B&I 4X4X4X
Delayed B&I 1X1X1X
Urea 1X
Urea 2X
Urea 4X
Treatment

Fig 3.6

SOIL PROPERTIES IN THE FALL OF 2008

While the urea added at the high rate resulted in a soil pH decrease of about 0.3 units compared to the low rate and control, the cattle manure treatments had little or no influence on pH, consistent with findings in soils sampled in the fall of 2007. The soil salinity was not significantly affected by cattle manure addition, but all E.C. values including the control tended to be somewhat elevated, at ~ 1 mS/cm. The reason for this is not clear but could be due to dry fall conditions and increased evaporation from the soil surface. This was not observed in 2007.

As in previous years, nitrate contents were only slightly elevated in cattle manure application treatments. The 4X treatment applied every year had the highest nitrate content in the 0-30cm depth of 26 kg nitrate-N/ha compared to 11 kg /ha in the control. The residual nitrate in this treatment in fall of 2008 is much less than in 2007 where it was 90 kg/ha. This reflects greater usage of nitrate by the canola grown in the 2008 season, leaving less nitrate behind and points to the value of growing high nutrient using crops like canola in keeping soil nitrate levels down in manured soils. There was no evidence of significant elevation of nitrate in the 30-60cm depth, even in the 4X annual cattle manure application treatment made for the last eleven years.

The greatest effects of the cattle manure addition appear in the soil extractable P and K. All the treatments applied every year have significantly elevated modified Kelowna extractable P (Figure 3.7), as in past years. The 4X annual application rate has ~ 250 kg MK P / ha 0-30cm. Extractable K 0-30 cm was also almost tripled over the control in the 4X annual cattle manure treatment. Less frequent and lower application rates are required to avoid P loading i.e. 1X, 2X-0, or 4X-0-0.

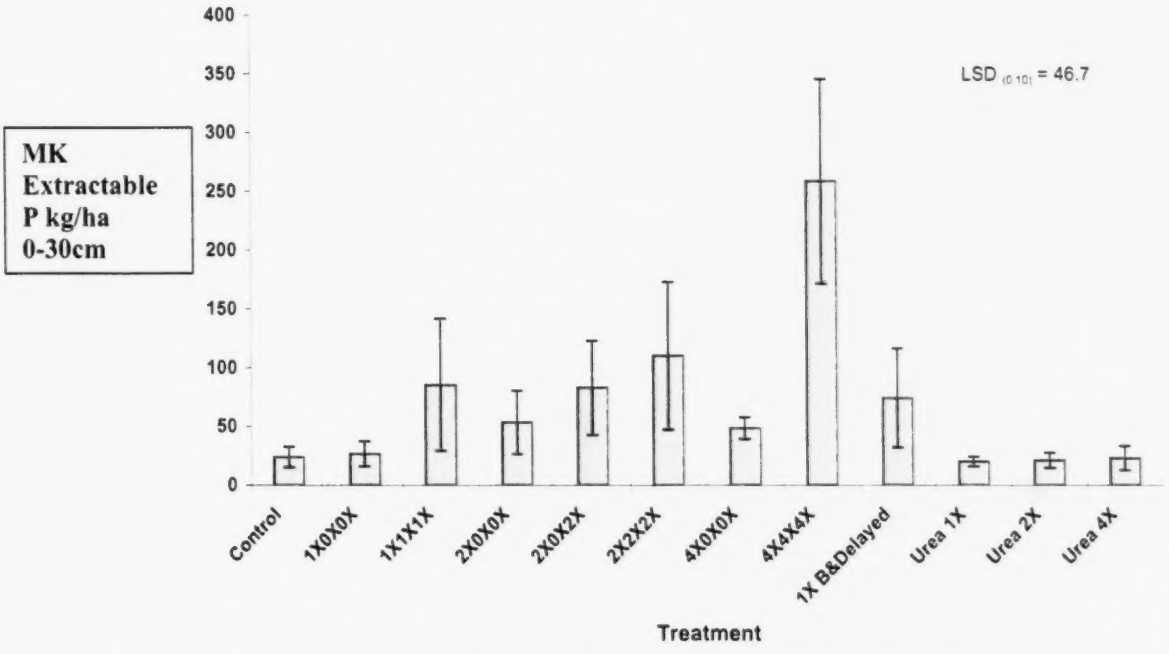


Figure 3.7. Soil test extractable (modified Kelowna) phosphorus (0-30cm) in Dixon LT cattle manure trial.

Long-Term Liquid Swine Manure Trial, MELFORT, SK

2008 Agronomic Results

CANOLA YIELD

As at the Dixon site in 2008, there was a good yield response (near doubling) of canola grain yield at Melfort to manure amendment compared to the unfertilized, unmanured control treatment. The carryover effect of the 3X rate (9000 gpa) applied 2 years previously in 2006 was evident. The highest yield was in the 2X treatment. The urea treatment did not yield much: only ~ 200 kg/ha of seed yield was produced due to extreme S deficiency. Sulfur fertilizer (elemental and potassium sulfate) was applied (broadcast) at a rate of 40 kg S/ha to the two strips in the spring of 2008. These had previously received S at 40 kg S/ha in 2005, and in 2002. In response to the S fertilization, the canola grain yield of the urea treatment increased from 200 kg /ha to 1380 kg/ha in the elemental S fertilized treatment and to 2300 kg/ha in the sulfate fertilized urea treatment. The response of the swine manure treatments to supplemental S was more limited, with only the sulfate applied to the 2X treatment showing any benefit, and even a trend to lower yield in the elemental S fertilizer treatments.

CANOLA NUTRIENT

Trends in canola nutrient contents in 2008 were similar to the effects of manure on barley in 2007. Canola grain N concentration was highest in the urea treatment, and was significantly higher than the control in the 1X annual and 2X-0-2X treatment. The 3X-0-0 treatment had grain and straw N concentrations similar to the control, indicating that two years following application, the N benefit had diminished significantly. The swine manure did not have a large effect on grain or straw P concentrations, similar to 2007 with barley. Grain S concentration was not greatly affected by manure application, and straw S concentration was significantly increased with addition of the liquid swine manure, indicating that the liquid swine manure is supplying available sulfur. Very low grain and straw S concentrations were observed in the urea treatments, reflective of severe S deficiency in the urea treatment.

Addition of the sulfur fertilizers greatly increased the grain and straw S concentrations. This was especially true for the sulfate source, reflecting its greater availability compared to the elemental source which must be oxidized to sulfate microbially before it is rendered available for use. The large increase in grain and straw S concentration is consistent with the large grain yield response of canola to the S fertilization of the urea treatment. Lack of yield response to S addition in the liquid swine manure plots indicates the liquid swine manure supplied sufficient S in 2008.

SOIL PROPERTIES IN THE FALL OF 2008

As in past years, the soil pH was relatively unaffected by treatment. The soil E.C. (salinity values) were very low, and were not significantly affected by treatment. Overall, nitrate levels in the 0-30cm and 30-60cm depth were all low and similar among treatments, suggesting that none of the treatments would lead to large nitrate migrations off site with snowmelt water.

Again it is concluded based on 2008 results, that there appears to be no issue with nitrate loading at this site with any of the treatments. As observed in 2007, and again in 2008, the extractable soil phosphate levels in the manured treatments tend to be lower than the control, and lowest in the urea treatment where no P fertilizer but S fertilizer was added. Addition of S fertilizer, especially sulfate, increased the soil sulfate content in all treatments as expected. Ammonium contents were elevated in the potassium sulfate treatments, perhaps reflecting displacement of clay interlayer ammonium by the added potassium.

2009

Raw (Unprocessed) Liquid Hog Manure vs Biodigestate Trial, Dixon, SK

2009 Agronomic Results

OAT YIELD

Compared to the Melfort site in 2009, the oat grain yields at the Dixon site were lower although straw yields were similar. This may reflect greater moisture stress, but more likely the effects of some hail damage from a hail storm in late July at the site that produced some visible damage. There were significant yield responses to addition of the two manure sources at the 1X (1500gpa), 2X (3000gpa) and 4X (6000gpa) rates. There was little benefit to yield from exceeding the 2X (3000gpa) rate, similar to responses observed for oats in 2007 and canola in 2008, although straw yields continued to increase up to the 4X rate. The urea treatment yields were similar to manure yields, indicating that apart from N, deficiencies of other nutrients for the oats were relatively minor. This is likely a result of the good ability of oats to scavenge nutrients like P from the soil. The responses observed at this site are similar to what has been observed in the first three years of the long-term study in 1997,1998 and 1999. However, it is anticipated based on results at the long-term site in the past few years, that after many years of N only addition by urea without any other nutrients, differences between manure and urea amended treatments become larger. This is because nutrients like P and S become more and more depleted in the urea treatment, but are maintained or are increased with repeated addition of manure containing these nutrients.

Of note were the significantly lower grain and straw yields of the 1X (1500gpa) biodigestate treatment versus 1X(1500gpa) raw liquid hog manure treatment. The 1X oat grain yield for biodigestate was ~2000 kg/ha versus ~3000 kg/ha for the raw LHM. This is explained by the raw manure having a higher N concentration than the biodigestate in 2009 and therefore a greater amount of nitrogen applied at the 1X (1500gpa) rate: 93 kg total N/ha and 66 kg available N/ha for raw LHM versus 24 kg total N/ha and 20 kg available N/ha for digestate. Less P and other nutrients were added in the biodigestate as well. If one considers that the 2X rate of biodigestate manure would apply slightly less available N and about the same amount of P as the 1X rate of raw manure and compare yields, we see that the yields are similar. Therefore, per unit of N and P added as raw versus biodigestate derived liquid hog manure, there appears to be little

difference in agronomic performance, consistent with the results observed for 2007 and 2008 crop seasons.

OAT NUTRIENT

Grain N concentration was significantly increased over the unfertilized control at the highest rates of addition (6000 gpa) of raw liquid swine manure and biodigestate. Urea addition increased the grain N concentration to a similar extent as the additions of the swine manure. For a given rate of liquid manure application, the raw liquid manure gave significantly higher grain and straw N concentrations. This is a result of the raw liquid manure in 2009 having a higher N content than the biodigestate. As pointed out in the yield section above, if one considers that the 2X rate of biodigestate adds slightly lower amount of nitrogen than the 1X rate of raw manure, comparison of these two treatments reveals similar concentrations of plant nitrogen. This supports findings of the previous two years that there is no apparent difference in crop recovery of nitrogen from raw liquid swine manure versus biodigestate when added at the same rate of N. Grain P was relatively unaffected by the addition of raw or biodigestate liquid manure, while the concentration decreased due to growth dilution in the urea treatment. Straw phosphorus concentrations decreased with both types of manure addition compared to the control, and decreased to the greatest extent in the urea treatment. Similar plant phosphorus concentrations between the two different manure types, as observed in the two previous years, suggests little difference in ability of plants to recover phosphorus from the two manure types.

SOIL PROPERTIES IN FALL OF 2009

Soil pH was reduced by about 0.4 to 0.5 pH units in the high rate (6000 gpa) liquid swine manure and high rate (200 lbs N/ac) urea treatments compared to the unfertilized control. This was also observed in the past two falls and is attributed to acidity produced during nitrification of ammonium. Similar to the past two years as well, soil salinity and organic carbon concentrations were not affected by the addition of manure or urea fertilizer. This is explained by the fact that only three years of manure application have been made on this site. There were no differences in effects of digestate versus raw manure on soil chemical properties when applied at the same rate.

Reflecting the higher N content of the raw liquid hog manure compared to the digestate applied for 2009, the surface (0-15cm) soil nitrate levels were higher in the 2X and 4X raw manure treatments versus the biodigestate. Extractable P levels were also slightly higher for the raw manure treatments, especially the 4X treatment. The highest surface soil nitrate content was encountered in the 4X urea treatment. Consistent with an excess amount of N applied in the 4X urea and 4X raw manure treatment, there was significant elevation of nitrate nitrogen content in the 15-30cm depth and the 30-60cm depths compared to other treatments. The elevation at depth was greatest in the 4X (200 lb N / acre) urea treatment, with nearly 100 kg nitrate nitrogen present in this depth. There was no evidence of any movement of P below the 0-15cm depth. Soil extractable K levels were also increased by manure addition, especially the raw liquid manure in the 0-15 cm depth. This is explained by the raw liquid manure having a potassium concentration approximately three times that of the biodigestate in 2009, such that for a given rate of manure application, much more K is added in the raw liquid manure.

Long-Term Liquid Swine Manure Trial, Dixon, SK

2009 Agronomic Results

BARLEY YIELD

The year 2009 is the thirteenth field season of the experiment. As in previous years, the barley grain and straw yield was significantly increased by application of liquid swine manure. Barley grain yield increased from about 1200 kg / ha in the unmanured, unfertilized control to about 3200 kg/ha in the 1X (3300 gpa or ~ 80-100 kg total N/ha) rate. There was no yield decrease above the 1X rate as was observed for oats at this site in 2007. Barley yield increases for rates of manure application above 1X (ie 2X and 4X) were smaller, but the highest barley grain yield (~4000 kg/ha) was observed at the 4X annual application rate. This likely reflects good growing conditions for barley at the site in 2009. Highest mean yield was also observed for canola at the 4X rate in 2008, although the canola yields were not significantly higher than the 2X rate.

There was no yield response of the barley to pre-plant banded P fertilizer addition (15 kg P_2O_5/ha) on the manured plots, as observed in previous years, indicating that the swine manure was supplying sufficient P. However, there was a large and significant response of barley grain and straw yield to P fertilization on the urea plots, as observed with canola in 2008, but not with oats in 2007. Oats are known to be good scavengers of nutrients. Barley grain yields on urea plots were increased by 400-600 kg/ha from P addition. This shows the large response that can be expected from P fertilization and the difference that P fertilization makes when fields have been mined for P by continuous cropping without replenishment of P supplies by addition of commercial fertilizer or manure.

In 2009, all plots received manure application, including alternate year (1X-0-0,2X-0-0,and 4X-0-0) treatments. Therefore it was possible to compare the effect of two previous years without swine manure application versus application every year at the same rate. The treatments where application was skipped the previous 2 years but applied in 2009 tended to yield slightly lower than repeated annual applications, reflecting the effects of some nutrient depletion during the two years in which manure was not applied, especially for the lower rates. It may be concluded that a treatment rate every year of 3000-5000 gallons per acre or double this rate every second year would be optimal for maximizing production for crops grown on these and similar Black soils.

Compared to urea only and the urea + P treatments, barley yields were higher on 1X, 2X and 4X hog manure treatments. This indicates that other constituents of manure in addition to N and P are contributing to yield benefit from the manure. Consistent with results of all twelve previous years of the study, higher grain and straw yields were observed for liquid manure injection versus broadcast and incorporation placement. This was especially evident for the hog manure without P fertilization treatments where the barley grain yield of injected (~3200 kg/ha) was substantially higher than broadcast and incorporated (~2400 kg/ha). Less benefit from injection when P fertilizer is banded suggests a benefit of injection for enhancing availability of P in the manure as well as N. This may be explained by the injection placing manure P closer to the roots and thereby improving root access to the P. These findings are supported by similar

observations in 2008 at the site, where response to supplemental banded fertilizer P was only observed in the broadcast and incorporation application treatment. Also, as in previous years (2005,2006,2007 and 2008), we did not see any benefit from the addition of dicyandiamide (DCD) nitrification inhibitor to the manure on the yield, as barley yields were nearly identical in the 1X treatment with DCD versus without.

BARLEY NUTRIENT

The effects of manure management on the concentrations of nitrogen and phosphorus in the barley grain and straw in 2009 were similar to those observed in the previous two years. The addition of liquid swine manure and urea resulted in increasing nitrogen concentration in the grain (protein), with the highest concentrations observed at the highest rates of urea and swine manure addition. The straw N concentrations were even more responsive to increased soil N availability from amendment with liquid manure or urea, with increases from about 0.3%N content in the straw of unfertilized treatments to about 0.6%N in the highest rates of urea and liquid swine manure. Grain and straw N concentrations and yield were very similar between the treatments with the nitrification inhibitor versus no inhibitor, indicating that again as in previous years, the nitrification inhibitor did not have an impact on manure N recovery by the crop. Higher plant nitrogen concentrations and yield in the injected versus broadcast and incorporated treatment indicate higher N recovery when the liquid manure is injected. This is consistent with all previous years of the long-term study.

Phosphorus concentrations in the grain and straw of the barley tended to decrease from the control to the low rate of liquid swine manure, but then increased again from the low to the high rates of liquid swine manure addition. The decrease likely reflects growth dilution effects. Some P is added in the liquid swine manure, so at high rates the P content of the grain and straw is higher compared to the low rates. The urea treatments, which have not had any P fertilizer added since 1996, showed much lower grain and straw P concentrations with 0.37%P in the grain of the control versus ~ 0.18%P in the grain of the 2X and 4X urea treatment. This again shows the effects of many years of addition of only nitrogen on the depletion of soil P fertility and subsequently reduced content in the grain. Both the liquid swine manure and urea treatments with P fertilizer banded annually at 15 kg P_2O_5 / acre showed significantly increased grain and straw P concentrations compared to treatments without P fertilization. The demonstrated ability of the manure to maintain high concentrations of both grain N (protein) and P is an important consideration, as both crop quality and yield factor into the benefits and economic returns from fertilization.

SOIL PROPERTIES IN THE FALL OF 2009

In contrast to the fall of 2007 and 2008, the pH in the 0-30cm depth was not affected by manure application. The only treatment to produce a decrease was the 4X urea treatment. Environmental conditions during 2009, especially the warm, dry extended fall period before sampling may have increased the upward movement of carbonates from depth with water evaporating from the surface. The carbonates would buffer acidity produced from nitrification. Also of note is that as in 2007 and 2008, the soil salinity was increased above 1.0 mS/cm in the 4X annual application treatment, with an E.C. of 1.3 mS/cm. Again this provides evidence that repeated application of liquid swine manure at excessive (4X or 13,200gpa per year) rates can lead to soil salinity.

Soil nitrate contents in the 0-30cm depth were only significantly increased above the control in the 4X annual application rate treatment and the 4X annual urea treatment. There was 60-120 kg nitrate nitrogen in these treatments compared to 10 to 20 kg/ha 0-30cm in the rest of the treatments. Furthermore, as observed in the previous year, there is nearly 300 kg nitrate nitrogen /ha in the 4X annual swine manure treatment in the 30-60cm depth and 150 kg nitrate-N/ha in the 4X urea treatment. Our deep sampling conducted in the fall of 2009 reveals significantly higher nitrate content in the 60-90 cm depth in the 4X swine manure and 4X urea treatments, reflecting some deep migration of nitrate over the years. In these treatments there was 70 to 100 kg / ha of nitrate N in the 60-90cm depth. In the 90-120cm depth of the 1X and 2X annual swine manure applications there was about 20-30 kg N /ha of nitrate present versus 6 kg/ha in the unfertilized control. However the 4X annual swine manure application treatment has about 85 kg/ha nitrate nitrogen in the 90-120cm depth and the 4X urea treatment has 63 kg /ha. Treatments with reduced application frequency, even the 4X-0-0, show little evidence of deep leaching of nitrate. This suggests that single large applications that result in residual unused nitrate after the first year may in fact be recovered by crops grown the following year when manure is not re-applied, thereby preventing nitrate from making its way deeper in the profile. However, residual nitrate at the surface would be susceptible to loss by denitrification in spring snow melt. Clearly, annual applications of liquid swine manure at rates in excess of 10000 gpa would be associated with concerns about excess nitrate slowing migrating down the soil profile below the root zone and eventually entering into subsurface aquifers. As noted in previous years, soil P loading is not an issue in these soils when applied at agronomic (1X or 3000-4000 gpa/yr) rates or higher rates applied less frequently. Only in the 4X application rate applied every year do we see a significant increase in soil extractable P. As in previous years, treatments receiving manure applications at frequent high rates or annually showed significant increases in soil extractable K, while long term addition of urea resulted in substantial depletion of soil extractable K. For example, compared to the unfertilized control with ~1050 kg extractable K / ha in 0-30cm depth, the 1X annual application (3300 gpa) has ~1250 kg K / ha while the 1X urea treatment has ~870 kg K/ha.

Long-Term Solid Cattle Manure Trial, Dixon, SK

2009 Agronomic Results

BARLEY YIELD

As observed in previous years, the application of cattle manure resulted in significant increases in barley grain and straw yield in 2009. Grain yields increased with application rate, from ~1200 kg/ha in the unfertilized control to 1800 kg/ha in the 1X annual (3.4 tons dry manure/acre), 2100 kg/ha in the 2X annual and 3700 kg/ha in the 4X annual application rate (Figure 3.8). Owing to lower availability of nutrients in cattle manure versus liquid swine manure, rates above the 1X application (~ 80 lbs N/acre) have been noted to be needed for maximum yield in previous years, such as 2X for oats in 2007 and 4X for canola in 2008.

It is interesting to note that yields of treatments where application was skipped the previous two years but manure applied for 2009 re: 1X-0-0-1X, 2X-0-0-2X, 4X-0-0-4X were lower in 2009 than 1X every year, 2X every year and 4X every year. With cattle manure,

repeated application every year at 2X and 4X rates appears to be necessary to maximize yield. However, manure alone at these rates results in excessive build-up of phosphorus in the soil. At lower rates of addition (1X), the urea yields were higher than cattle manure amended yields, but at higher rates (2X and 4X) these differences diminished. This indicates that at the lower rates of cattle manure addition (1X), low N availability is still limiting production potential even after 13 years of application.

The broadcast and 24 hour delayed incorporation of cattle manure treatment yielded slightly lower than broadcast and immediate incorporation, although the difference was not statistically significant. These results are consistent with the results of all previous years of the study where a 24 hour delay of incorporation had relatively little impact on agronomic parameters. This can be explained by the low content of volatilizable nitrogen compounds such as ammonium present in this cattle manure, comprised of a mixture of fecal material and bedding straw that has been stockpiled for about one year prior to spreading. In this manure, almost all of the nitrogen is present in the organic form, a form that is not susceptible to ammonia gassing off.

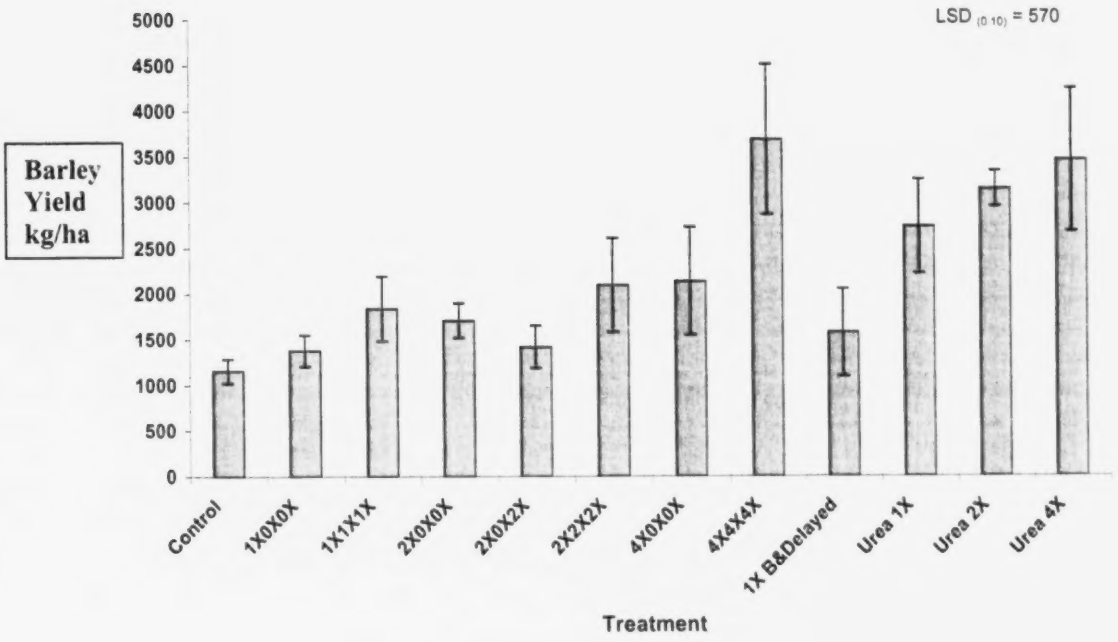


Figure 3.8. Barley grain yield in 2009 Dixon LT cattle manure trial.

BARLEY NUTRIENT

Grain and straw N concentrations were increased by additions of cattle manure and urea as in previous years. Highest grain and straw N concentrations were found in the 4X treatments of urea, with ~1.5%N in the barley grain. Lower N contents in grain of barley are desirable for malting purposes. Cattle manure addition increased the barley grain and straw N content to a greater extent than P content. Highest N concentrations were observed at the 4X rate of manure, but P contents were not greatly affected. In the previous years, P content in the crop was highest at the high rate of manure addition. As in previous years, there was no significant difference in grain N or straw N between the broadcast and immediate incorporation versus the broadcast and 24 hour delayed incorporation treatment. The lack of effect of delayed incorporation on N recovery is attributed to low content of volatilizable ammonia in this cattle manure source.

SOIL PROPERTIES IN THE FALL OF 2009

Soil pH was not significantly affected by cattle manure application, similar to results observed in the fall of 2008 and 2007. Similar to the liquid swine manure trial in 2009, the only treatment to have significantly lower pH than the rest of the treatments was the 4X urea treatment. As noted in 2008, the E.C. values in all treatments were slightly elevated in 2009, with E.C. values around 1.3 to 1.5 mS/cm in the 2X (7 tons dry manure / acre) and 4X annual application rates. However, there is quite a high degree of variability in the E.C. values, making significant differences difficult to reveal. Overall, across the site a higher background level of salinity appears to exist compared to the long-term swine manure site, as the control treatment plots without manure or fertilizer had E.C. values around 0.7 mS/cm in the cattle manure trials.

In the 0-30cm depth, there were no significant differences in nitrate content among treatments, except for the 4X urea treatment which had ~90 kg nitrate nitrogen /ha compared to ~ 15 kg /ha for the rest of the treatments. This reflects the relatively slow nature in which cattle manure N, almost exclusively in organic form, is converted to inorganic forms of ammonium and nitrate. The 4X rate annual application treatment of cattle manure shows some small elevation of nitrate below 60 cm, all the way to 120cm. However, as in the urea treatments in the swine manure trials, the 4X (200 lbs N/ac) annual application of urea results in very large accumulations of nitrate deeper in the profile. There is ~ 350 kg/ha of nitrate in the 30-60cm depth and another ~ 100 kg / ha in each of the 60-90cm and 90-120cm depth increments of the 4X urea treatment compared to amounts of ~ 10 kg/ha in the cattle manure treatments. Overall, the risk of nitrate leaching appears to be significantly less with high loads of cattle manure nitrogen than with liquid swine manure N or urea. On the other hand, as observed in previous years, application of cattle manure quickly leads to accumulation of extractable P in the soil. Cattle manure addition has a very large impact on both extractable phosphorus and potassium content in the soil. For example in the unfertilized, unmanured control there is ~ 36 kg extractable P/ha in the 0-30cm depth, while the 1X (3.4 tons dry manure/acre/year) has 155 kg extractable P/ha, while the 4X annual application rate has ~400 kg extractable P / ha in 0-30 cm depth. Applications of higher rates (2X) every second year (~92 kg extractable P/ha) or 4X every third year (~215 kg extractable P / ha) reduce the rate at which the soil loads up with phosphorus. It is evident that soil P loading can occur very rapidly and to a great extent when cattle manure is land applied. Similarly, although not of environmental concern, the addition of cattle manure at the 4X rate for 13 years resulted in a three fold increase in soil extractable K over the urea and unfertilized control treatments.

Long-Term Liquid Swine Manure Trial, MELFORT, SK

2009 Agronomic Results

OAT YIELD

The 1X annual application rate of liquid hog manure produced an oat grain yield of ~6000 kg/ha in 2009 (Figure 3.9). The 3X rate that was preceded by two years without manure application produced a slightly, but not significantly higher yield of ~ 6500 kg/ha. The 3X rate + elemental S produced the highest yield of 7300 kg/ha (Figure 3.9) The sulfur fertilizer treatments of 40 kg S/ha as elemental S or potassium sulfate were applied in the spring of 2008, and some residual effects of increased sulfur availability in 2009 associated with oxidation of residual elemental S may have occurred. The residual effect of the 2X treatment of manure made in 2008 (2X-0) was evident in 2009 with ~ 4200 kg/ha oat grain yield versus 2800 kg/ha in the unmanured, unfertilized control. Still, as observed with barley in 2007, yields with the 2X-0 were not as good as the 1X annual rate. The 1X annually applied rate appears best in maximizing crop production over the years versus doubling up every two years. This may be because excess nutrient left after the first year of a high application rate is subject to additional losses from the system, especially under higher moisture conditions in Gray-Black soils such as these.

The commercial urea fertilizer treatment (80 kg N/ha) performed quite well, with an oat grain yield of about 6000 kg/ha, which was better than for barley in 2007. As for the 3X liquid swine manure treatment, the highest oat yields for urea were found with the urea + elemental S. Responses of canola, and oat to supplemental S fertilizer have often been observed at this site in previous years. The results in 2009 suggest a significant second year benefit from elemental S applied the year earlier for both the urea and high swine manure rate treatments. However, as noted previously, the benefits of supplemental fertilizer S with liquid swine manure are variable from year to year, and also with S fertilizer form, as sulfate seemed to have no apparent benefit this year, but has shown greater benefit than elemental S in some previous years of the trial.

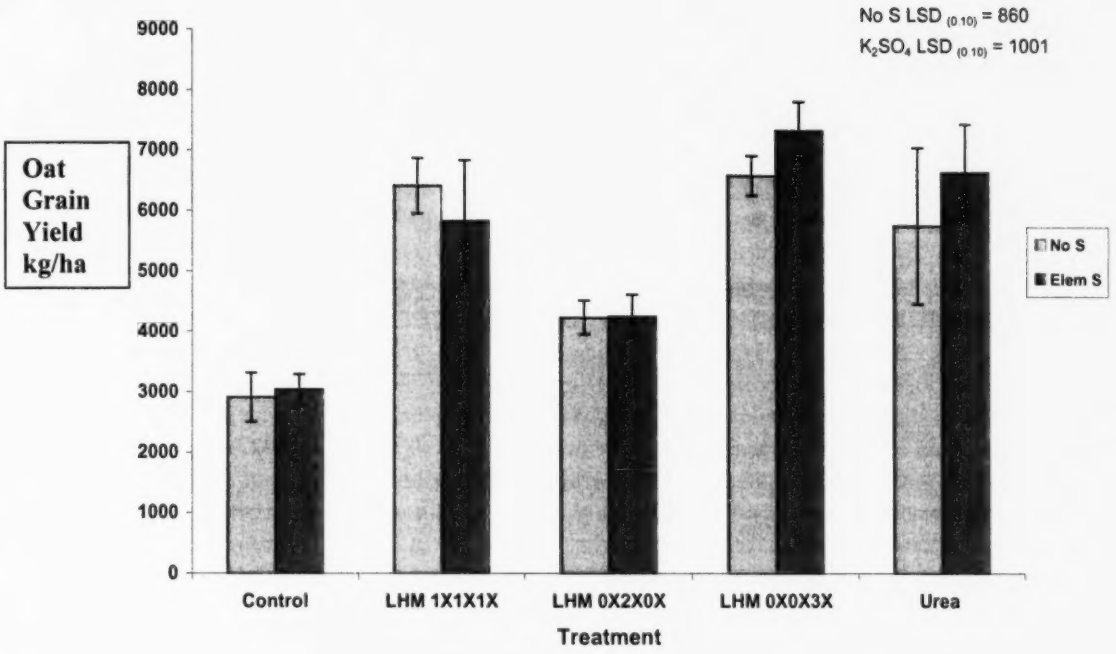


Figure 3.9. Oat yield without and with supplemental fertilizer sulfur in 2009 at Melfort LT swine manure research trial.

OAT NUTRIENT

The nitrogen content of the oat grain was significantly increased by liquid swine manure addition in a manner similar to previous years, and similar to effects observed at the Dixon long-term site. Annual addition of liquid swine manure at the 1X rate (3300 gpa) at this site resulted in higher N concentration of the oat grain and straw than the 2X (6600 gpa) rate applied every second year, with no application made in 2009. This indicates that lower N availability may be expected in the second year of the "double up" approach and may limit production in the second year versus the 1X annual rate. There was no significant effect of the manure applications on grain P, but straw P concentrations decreased with manure or urea application compared to the unfertilized control due to growth dilution. This reflects a relatively low addition of P in the swine manure and is consistent with observations made in 2008 for canola and 2007 for barley.

The sulfur content of oat grain and straw increased with swine manure application as compared to the unfertilized control. These results are similar to observations made in 2008 with canola grain and straw sulfur content, and indicate that the swine manure is supplying some available S. The residual effect of the addition of the supplemental commercial S fertilizer in spring 2008 was not evident in the sulfur content of the oat grain harvested in 2009, as there was little difference in S content between the S fertilized and unfertilized oat grain. Compared to the large effect of S fertilizer addition on plant S concentration observed for canola in 2008 at this

site, the oat straw sulfur concentrations were not greatly affected by the S fertilization treatment. This likely reflects lower requirement of oat for sulfur and that the effects of S fertilization were residual from the 2008 application. Highest straw S concentrations were observed in the elemental S treatments, likely because elemental S is a slow release form that can supply available S via oxidation beyond the year of application.

SOIL PROPERTIES IN THE FALL OF 2009

At the Melfort site, addition of liquid swine manure and urea was associated with slightly lower soil pH in 2009 but the differences were small: only on the order of about 0.1 to 0.2 pH units lower. This is consistent with the findings in 2008 and 2007, which showed little effect. Sulfur fertilizers like ammonium sulfate and elemental sulfur produce acidity upon oxidation, but it appears that the acidity produced is buffered by bases present in the soil and also is perhaps not sufficient to detect in a 0-30 cm depth sample. As noted before, the E.C. values of the surface soil are low (<0.2mS/cm) and uniform across the treatments. The site is highly leached and therefore any added manure salts are likely rapidly moved below the rooting depth with percolating water.

In previous years, the fall soil nitrate levels were noted to be low (<10 kg nitrate-N/ha) in all treatments, with only slight elevation in treatments that had received manure application for that year. The same trend is observed in the fall of 2009. Only the 3X treatment (9900 gpa) had elevated nitrate (~15 kg NO3-N/ha versus < 10 kg/ha) in the rest of the treatments. Below this depth in the 30-60cm and 60-90cm layers, the soil nitrate and ammonium contents were similar. These results indicate that for the same amount of manure applied, 3300 gpa per year, double this every second year, or triple this (9900gpa) every third year, which averages out to around ~80 lb N/acre per year, there is no apparent issue with movement of nitrate and accumulation below the root zone. This is in agreement with results observed at the Dixon LT site. As observed and discussed for the fall 2007 and 2008 soil analysis, there is no concern about phosphate loading of the soil. As well, extractable potassium levels are relatively unaffected by liquid swine manure application. This is consistent with lower rates of manure addition at this site (3300 gpa every year or double rate every second, or triple this rate every third year) compared to treatments at Dixon where 6600 gpa and 13,200 gpa is added every year. The extractable K levels in the potassium sulfate treatment are slightly elevated compared to the elemental S and no S fertilizer treatments. The urea treatments have the lowest extractable soil K levels. As in 2008, the fall 2009 residual soil sulfate levels were higher in the sulfur fertilized treatments than the unfertilized treatments, with the highest sulfate levels in the treatments with sulfate as the added sulfur source versus elemental S. This likely reflects incomplete oxidation of the added elemental S fertilizer to sulfate. Also, treatments with added fertilizer sulfur, especially sulfate fertilizer, had higher amounts of sulfate in the subsoil 30-60cm and 60-90cm depths. This is indicative of some deep leaching of sulfate in these soils. There were no apparent significant differences in surface soil sulfate content among the manure treatments, although all tended to be lower than the unfertilized control, presumably due to greater plant uptake of sulfur due to increased crop growth induced by the manure addition.

3.2 GREENHOUSE GAS, NUTRIENT SUPPLY RATES AND PHYSICAL PROPERTIES INCUBATION STUDY

Greenhouse Gases

Nitrous Oxide Gas Evolution

The Dixon long-term site N_2O gas evolution over the ten day incubation period showed production for the DXLTH (Dixon Long-Term Hog) 2X and DXLTC (Dixon Long-Term Cattle) 2X treatments that were not different from the unfertilized, non-manured control treatment (DXLTHCD) (Figure 3.10). The long term CD (Control Disturbed) N_2O gas evolution was low and similar to the hog and cattle manure treatments except for a small peak of 0.06 μg N_2O cm^{-2} h^{-1} on the third sampling period. The Dixon long-term urea treatment showed higher overall N_2O gas evolution compared to the other treatments (Figure 3.16). The urea treatment N_2O gas evolution increased to 0.09 μg N_2O cm^{-2} h^{-1} by the second sampling day, decreased slightly for the third and fourth sampling dates and then increased to 0.11 μg N_2O cm^{-2} h^{-1} by the last sampling date. Some of the N in the urea treatment would have been used by the crop by the time the cores were taken in the fall. However, there may have been residual inorganic N that could undergo denitrification.

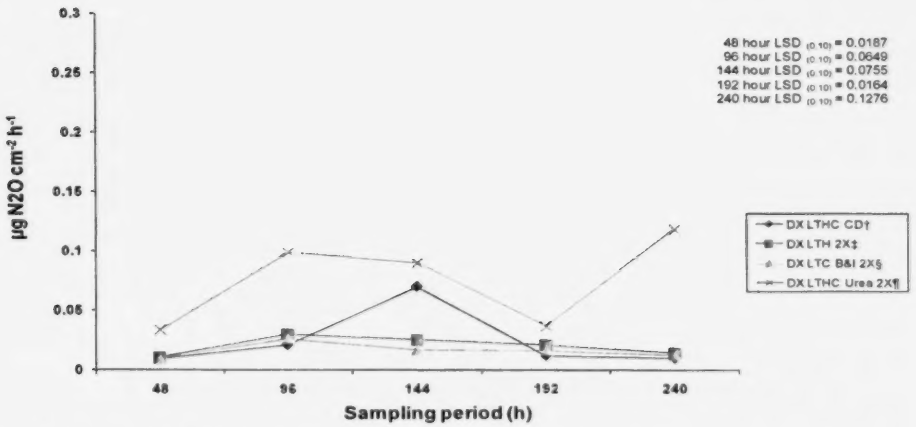


Figure 3.10. Dixon long-term site mean 48 hour N_2O gas evolution over a ten day incubation period.

†Dixon long-term hog and cattle manure site disturbed control treatment.
‡ Dixon long-term site liquid hog manure 2X application treatment.
§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.
¶ Dixon long term site urea fertilizer 2X treatment.

A lower supply of nitrate in the LT urea treatment (Figure 3.19) suggests consumption of nitrate over the ten day incubation period by denitrification. The DX LTC treatment would have to rely on organic N mineralization and would take more time to convert to plant available inorganic N.

The Dixon Biogas and SCM injection site N_2O gas evolution over the ten day incubation period showed very little evolution for the control treatments except for a spike in gas production to 0.09 μg N_2O cm^{-2} h^{-1} on the second sampling date for the CLH treatment (Figure 3.11). The SCM B&I 2X, SCM INJ 2X and BG urea 2X treatments showed a spike in N_2O gas evolution from the fourth to the fifth sampling date. The SCM broadcast and incorporation treatment N_2O gas evolution was significantly ($p \leq 0.10$) higher than any of the other four treatments. In previous work with manure in Saskatchewan, injection has been found to result in higher N_20 production than broadcast when measured in the field shortly (24 hrs) after application. However, in this current comparison, surface application was higher and may be a function of measurement of N_20 production in samples collected in the fall, several months after application was made in the spring.

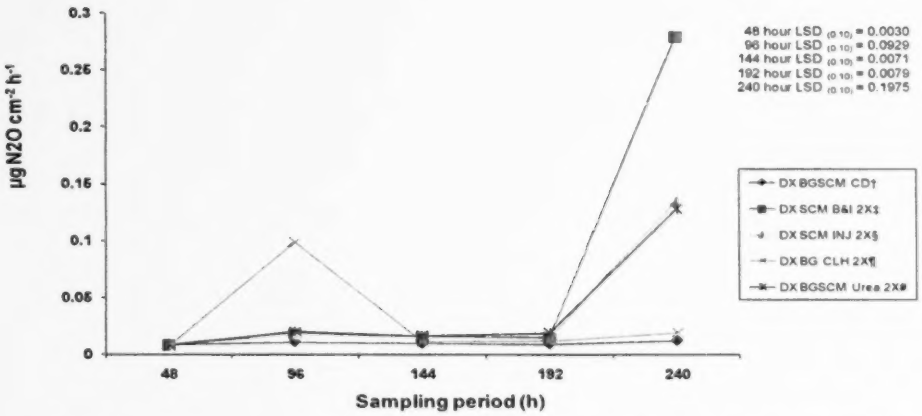


Figure 3.11. Dixon short-term Biogas and SCM site mean 48 hour N_2O gas evolution over a ten day incubation period.

†Dixon short-term Biogas and SCM site disturbed control treatment.

‡ Dixon short-term short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.

§ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.

¶ Dixon short-term Biogas and SCM site Cudworth liquid hog manure 2X treatment.

Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.

The Melfort site N_2O gas evolution over the ten day incubation period showed little production in the control treatment, except for an increase between the fourth and fifth sampling period (Figure 3.12). The urea and LHM 2X treatments produced amounts of N_2O gas that were similar to one another and slightly higher when compared to the control treatment, except for the last sampling date. It is noteworthy that urea fertilizer that was added at the start of the growing season resulted in higher N_2O gas evolution in the soil samples collected in the fall after the cropping season. Manure application also tended to increase N_2O gas production measured in the fall in the Dixon ST site and at Melfort, but not in the Dixon LT site. Elevated soil NO_3 supply in the Dixon ST Biogas and SCM Injected site and at Melfort may reflect more N_2O gas produced

by nitrification in which ammonium is oxidized to nitrate, and nitrous oxide is produced as a consequence.

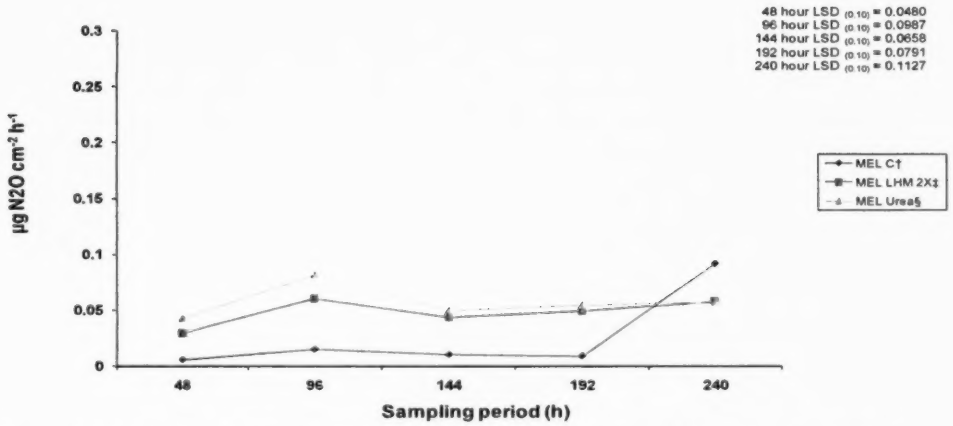


Figure 3.12. Melfort site mean 48 hour N_2O gas evolution over a ten day incubation period.

†Melfort site control treatment.
‡ Melfort site liquid hog manure 2X treatment.
§ Melfort site urea fertilizer treatment.

Carbon Dioxide Evolution

The Dixon long-term site CO_2 gas evolution over the ten day incubation period showed an increase in CO_2 production from under 100 µg CO_2 cm^{-2} h^{-1} at the first sampling date to between 180 and 250 for all four treatments for the remaining four sampling dates (Figure 3.13). After the increase in CO_2 gas evolution from the first to the second sampling date, CO_2 gas evolution remained relatively constant for all four treatments. The control and cattle manure treatments had lower CO_2 gas production than the hog manure and urea fertilizer treatments.

In work conducted in the late 1990's, a similar large initial increase in CO_2 production followed by a gradual decrease was observed in field samples obtained 3-7 days after urea fertilizer, LHM and SCM were applied at Dixon, SK. A decline in CO_2 respiration would be expected as microorganisms oxidized organic components like sugars and soluble proteins until the supply is exhausted, and they then turn to decomposing recalcitrant material such as cellulose and lignin, at which point microbial activity and thus CO_2 respiration will be retarded and stabilize at a low level. In field CO_2 gas samples taken at the Dixon LT site in the late 1990's it was found there were no significant differences in CO_2 evolution between urea, LHM or SCM treatments and it was theorized that the readily degradable organic material is oxidized within 2 weeks of application. In the current study, the intact soil cores were obtained in October 2008, one year after the last of eleven successive applications of urea fertilizer, LHM and SCM had occurred. The increase in CO_2 respiration between 48 h and 96 h and stabilization for the remainder of the incubation period suggests that after the initial period, there was slow decomposition of more recalcitrant material.

The Dixon short-term site CO_2 gas evolution over the ten day incubation period showed a similar pattern compared to the long-term site, with CO_2 production being lowest in the control treatment (Figure 3.14). Carbon dioxide gas production increased from under 100 μg CO_2 cm^{-2} h^{-1} at the first sampling date to 129 μg CO_2 cm^{-2} h^{-1} for the control treatment and over 200 μg CO_2 cm^{-2} h^{-1} for the SCM B&I 2X, SCM Injected 2X , CLH 2X and urea 2X treatments. The control treatment followed the same CO_2 gas evolution pattern as the CLH 2X treatment over the 10 day (240 hr) incubation period, however, producing a lesser amount of CO_2 gas.

The Melfort site CO_2 gas evolution over the ten day incubation period showed an increase in gas production from between 35 μg CO_2 cm^{-2} h^{-1} for the LHM 2X treatment and 54 μg CO_2 cm^{-2} h^{-1} for the urea treatment on the first sampling date to 112 μg CO_2 cm^{-2} h^{-1} for all three treatments on the second sampling date (Figure 3.15). Carbon dioxide gas production slightly decreased for all three treatments for the third and fourth sampling dates. There were no significant differences in CO_2 gas evolution between the three treatments over the ten day incubation period. Moist soil conditions at the Melfort site , that would hasten substrate decomposition, coupled with manure and urea fertilizer application made back in the fall of 2007 nearly a year ago, may explain the lack of any treatment effect on CO_2 gas production.

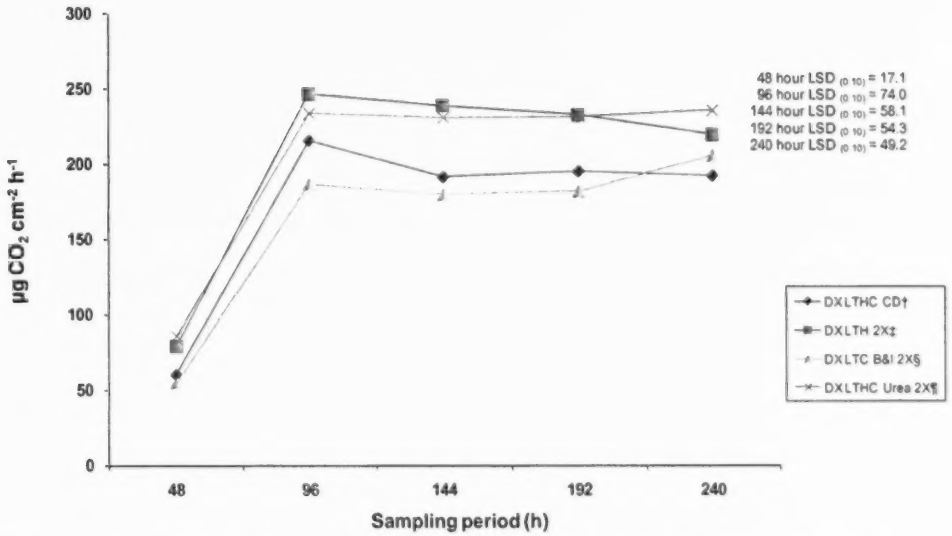


Figure 3.13. Dixon long-term site mean 48 hour CO_2 gas evolution over a ten day incubation period.

†Dixon long-term site hog and cattle manure disturbed control treatment.

‡ Dixon long-term site liquid hog manure 2X application treatment.

§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.

¶ Dixon long term site urea fertilizer 2X treatment.

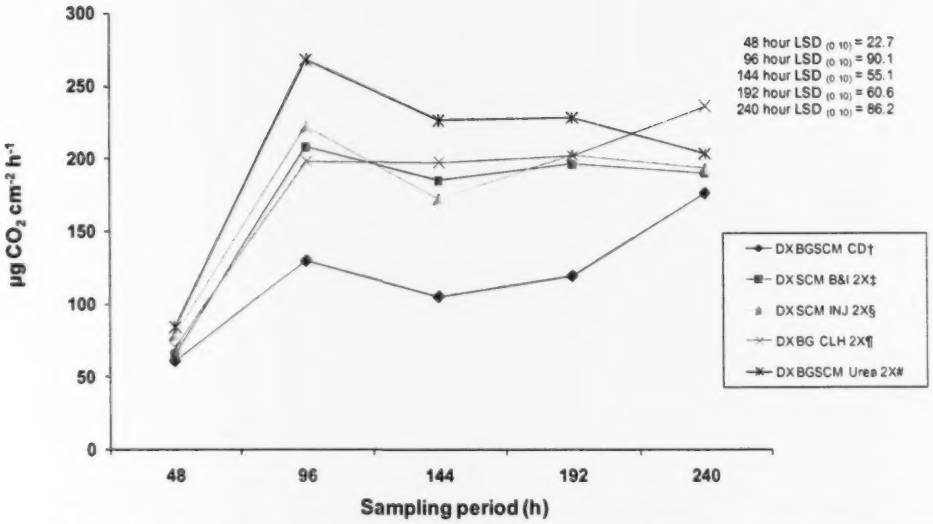


Figure 3.14. Dixon short-term biogas and SCM site mean 48 hour CO_2 gas evolution over a ten day incubation period.

†Dixon short-term Biogas and SCM site disturbed control treatment.

‡ Dixon short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.

§ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.

¶ Dixon short-term Biogas and SCM site Cudworth liquid hog manure 2X treatment.

Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.

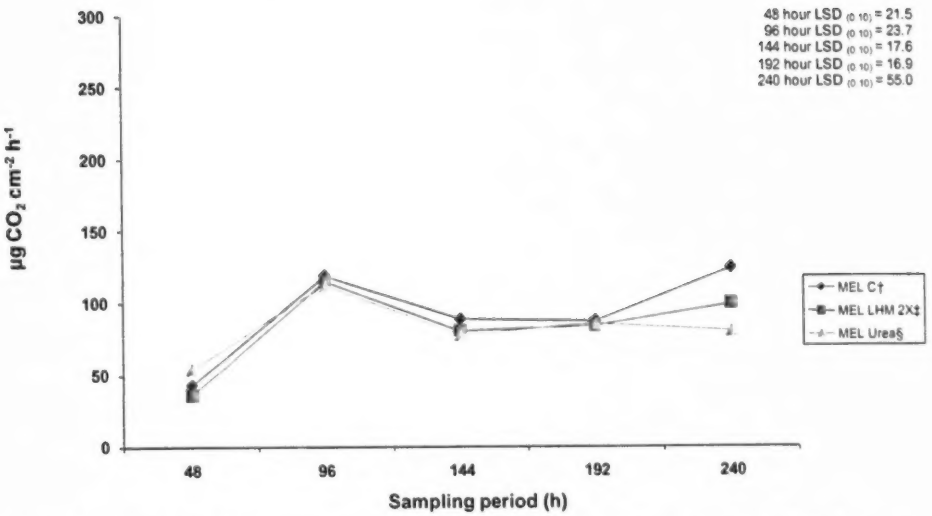


Figure 3.15. Melfort site mean 48 hour CO_2 gas evolution over a ten day incubation period.

†Melfort site control treatment.
‡ Melfort site liquid hog manure 2X treatment.
§ Melfort site urea fertilizer treatment.

All three sites showed similar trends (with noted exceptions) in CO_2 gas evolution over the ten day incubation period. There tended to be an increase in CO_2 gas production from the first to second sampling dates for all three sites. Carbon dioxide gas evolution then tended to level off or slightly decrease for most of the treatments at all three sites. This suggests that microbial activity increased during the initial stages of the incubation experiment as the microbial population acclimatized to the incubation conditions, producing more evolved CO_2 gas, and then levelled off or even slightly decreased over the remainder of the incubation period as substrate was consumed.

Cumulative Gas Evolution

Cumulative N_2O gas evolution over the ten day incubation period showed that the urea treatment in the Dixon long-term site produced the overall greater amount of N_2O followed by the Melfort urea treatment and Dixon BG and SCM B&I2X treatment (Figure 3.16). The Dixon short term B&I and Injected cattle manure treatments produced more N_2O gas over the ten day period than the Dixon long-term cattle manure treatment B&I. However, the annual rates of application of SCM are higher in the short-term study than the long-term study. The Dixon short term CLH 2X hog manure treatments produced more N_2O gas over the ten day period than the Dixon long-term DXH 2X hog manure treatment (Figure 3.16). This suggests that applications of manure could produce more N_2O gas in the first few years of application compared to long-term application sites. There was no evidence for greater evolution of N_2O in long-term application

treatments. However, a long term site like Melfort did show cumulative N_2O gas evolution over the ten day incubation period for the LHM 2X treatment to be more than double that for the Dixon long-term site. The Melfort site is located in the Gray-Black soil zone and has a higher content of OM compared to the Dixon site (Figure 3.16). The greater amount of substrate material for microorganisms combined with the addition of N in the form of LHM and urea could allow for more microbial activity and release of N as N_2O gas.

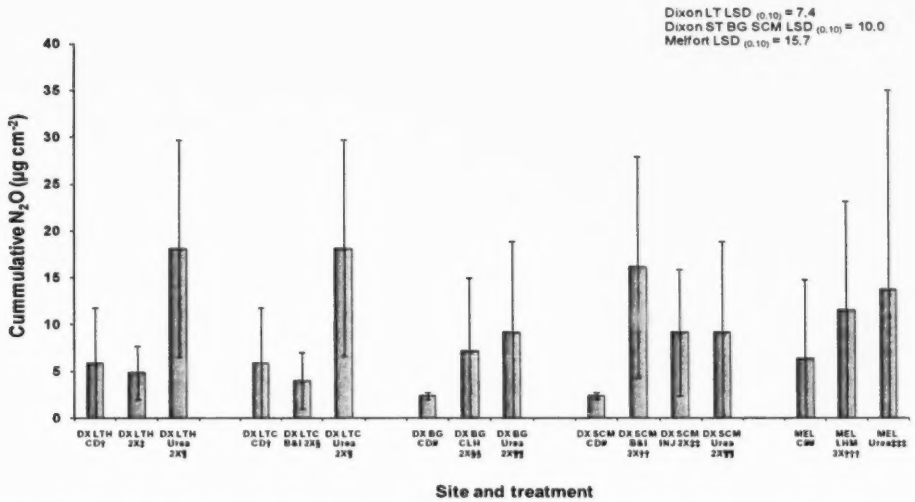


Figure 3.16. Cumulative N_2O gas evolution over a ten day incubation period at the Dixon long-term and short-term sites and Melfort site.

† Dixon long-term hog and cattle manure site disturbed control treatment.

‡ Dixon long-term site liquid hog manure 2X application treatment.

§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.

¶ Dixon long term site urea fertilizer 2X treatment.

#Dixon short-term Biogas and SCM site disturbed control treatment.

†† Dixon short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.

‡‡ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.

§§ Dixon short-term Biogas and SCM site liquid hog manure 2X treatment.

¶¶ Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.

Melfort site control treatment.

††† Melfort site liquid hog manure 2X treatment.

‡‡‡ Melfort site urea fertilizer treatment.

Cumulative CO_2 gas evolution over the ten day incubation period showed that the Dixon long-term site produced the most CO_2 gas in the urea treatment and DXH 2X LHM treatment, although this production was not significantly different from the other long-term treatments (Figure 3.17). The short-term urea treatments produced a similar amount of CO_2 gas over the ten day period compared to the long-term sites. The Dixon short-term SCM B&I 2X, Injected 2X and LHM CLH 2X all produced similar amounts of CO_2 gas over the ten day period, and were higher than the control treatment, concomitant with N_2O and NO_3 supply rate.

The Melfort site CO_2 gas evolution (Figure 3.17) over the ten day incubation period showed much lower amounts of CO_2 gas compared to the Dixon site. All treatments at Melfort produced similar amounts of cumulative CO_2 gas over the ten day incubation period and were not significantly ($p \leq 0.10$) different among treatments. However, N_2O gas production at Melfort was higher than Dixon. Therefore, activity of specific populations of microbes including nitrifiers and denitrifiers may have been greater at Melfort than Dixon. All sites had the same crop, canola, grown in 2008. So this does not provide an explanation. It may be that a lack of sulphur was limiting microbial activity and respiration at the Melfort site. The moisture levels in the Melfort soil cores were higher than the moisture levels in the Dixon long and short term site cores when the samples were collected from the field. Also the soils were more compacted, with less porosity in the Melfort cores. The excess moisture levels in the Melfort cores could have suppressed microbial activity and thus curtailed CO_2 gas evolution, while at the same time enhancing denitrification conditions allowing for more N_2O gas evolution over the ten day incubation period.

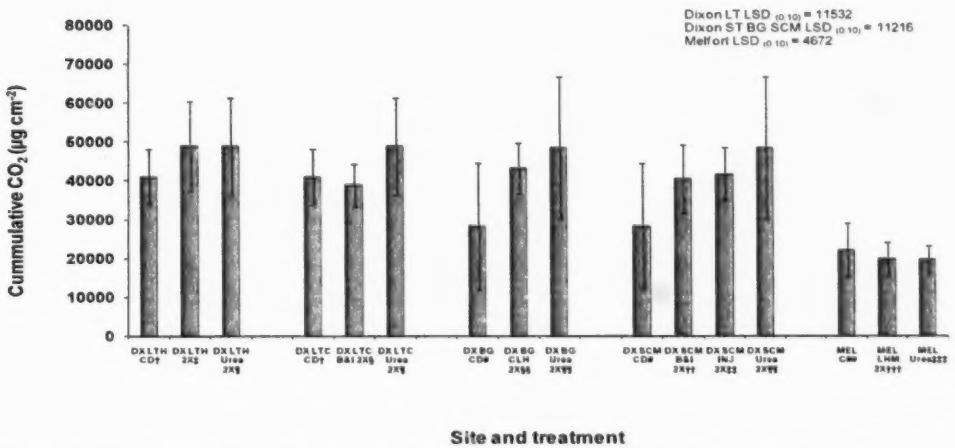


Figure 3.17. Cumulative CO_2 gas evolution over a ten day incubation period at the Dixon long-term and short-term sites and Melfort site.

† Dixon long-term hog and cattle manure site disturbed control treatment.

‡ Dixon long-term site liquid hog manure 2X application treatment.

§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.

¶ Dixon long term site urea fertilizer 2X treatment.

#Dixon short-term Biogas and SCM site disturbed control treatment.

†† Dixon short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.

‡‡ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.

§§ Dixon short-term Biogas and SCM site liquid hog manure 2X treatment.

¶¶ Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.

Melfort site control treatment.

††† Melfort site liquid hog manure 2X treatment.

‡‡‡ Melfort site urea fertilizer treatment.

Soil Nutrient Supply Rates

Soil Ammonium Supply

The Dixon long-term LHM and SCM site showed slightly greater soil NH_4 supply rates over the ten day incubation period compared to the Dixon short-term biogas and SCM site (Figure 3.18). Dixon LTH 2X showed the greatest amount of soil NH_4 supply, while the LTC B&I 2X treatment had the least amount of soil NH_4 supply. The Dixon short-term urea treatments had greater supply rates of NH_4 compared to the control treatment and the SCM B&I 2X and Injected 2X treatments. There were no significant differences between the control, LHM and urea treatments at the Melfort site (Figure 3.18).

Soil Nitrate-Nitrogen Supply

Soil NO3-N supply at the Dixon long-term site was found to be the greatest in the LTH 2X treatment (52 μg cm^{-2}) (Figure 3.19). The LTH 2X treatment is applied every fall season and contains more inorganic N versus the annually applied cattle manure treatment. The cattle manured treatment contains more organic N and takes a longer period of time to be converted and cycled into ammonium and subsequently nitrate forms. Thus the LTH 2X treatment was able to supply more N in the NO_3-N form compared to the cattle manure treatment.

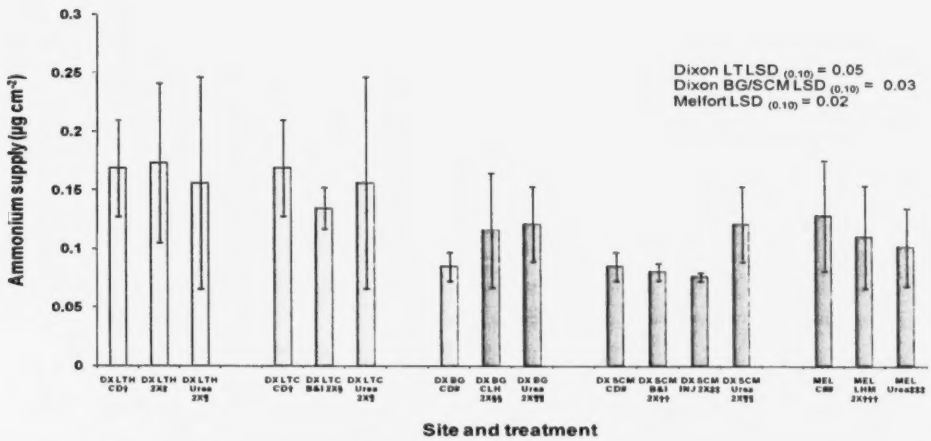


Figure 3.18. Dixon long-term and short-term sites and Melfort site intact soil core ammonium supply over 10 day incubation period.

† Dixon long-term hog and cattle manure site disturbed control treatment.

‡ Dixon long-term site liquid hog manure 2X application treatment.

§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.

¶ Dixon long term site urea fertilizer 2X treatment.

#Dixon short-term Biogas and SCM site disturbed control treatment.

†† Dixon short-term short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.

‡‡ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.

§§ Dixon short-term Biogas and SCM site liquid hog manure 2X treatment.
¶¶ Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.
Melfort site control treatment.
††† Melfort site liquid hog manure 2X treatment.
‡‡‡ Melfort site urea fertilizer treatment.

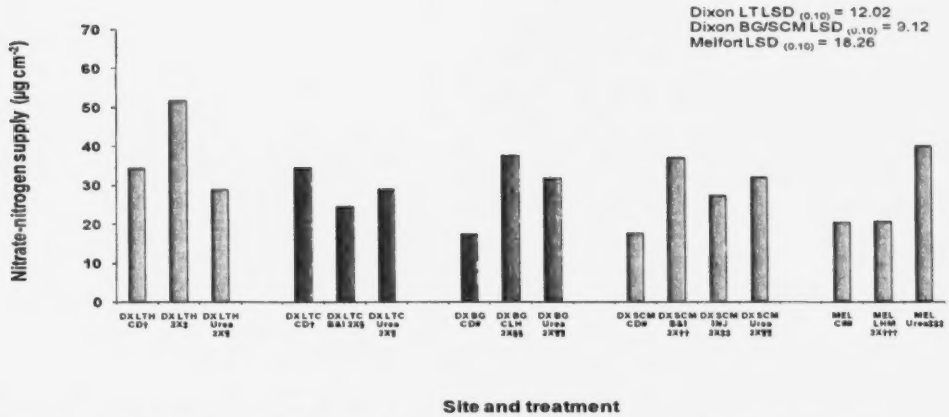


Figure 3.19. Dixon long-term and short-term sites and Melfort site intact soil core nitrate-nitrogen supply over 10 day incubation period.

† Dixon long-term hog and cattle manure site disturbed control treatment.
‡ Dixon long-term site liquid hog manure 2X application treatment.
§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.
¶ Dixon long term site urea fertilizer 2X treatment.
# Dixon short-term Biogas and SCM site disturbed control treatment.
†† Dixon short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.
‡‡ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.
§§ Dixon short-term Biogas and SCM site liquid hog manure 2X treatment.
¶¶ Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.
Melfort site control treatment.
††† Melfort site liquid hog manure 2X treatment.
‡‡‡ Melfort site urea fertilizer treatment.

At the Dixon short-term biogas and SCM injected site, the CLH 2X and SCM B&I 2X treatments produced 37 µg cm^{-2} of soil NO_3-N supply over the ten days (Figure 3.19). The SCM Injected 2X treatment produced a lower amount of soil NO_3-N. The SCM Injected 2X treatment is applied in a subsurface band with a small amount of water in order to facilitate proper subsurface application compared to the surface applied SCM B&I 2X treatment. Some of the nutrient in the injected band may have moved below the sampling zone of 10cm by fall, as the intact soil cores were obtained in the fall of 2008, at the end of the growing season.

Soil Phosphate Supply

Soil P supply was found to be the greatest in the cattle manure treatments at both the Dixon long-term and short term sites (Figure 3.20).

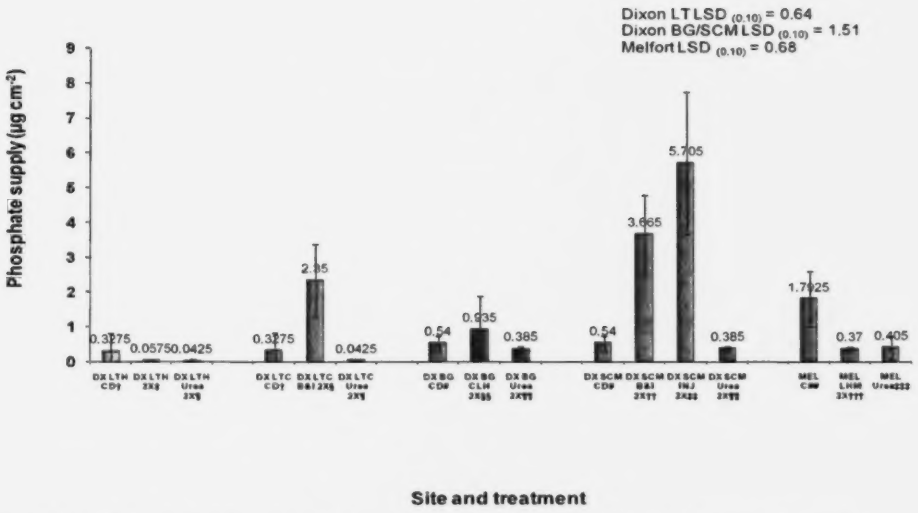


Figure 3.20. Dixon long-term and short-term sites and Melfort site intact soil core phosphate supply over 10 day incubation period.

† Dixon long-term hog and cattle manure site disturbed control treatment.

‡ Dixon long-term site liquid hog manure 2X application treatment.

§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.

¶ Dixon long-term site urea fertilizer 2X treatment.

Dixon short-term Biogas and SCM site disturbed control treatment.

†† Dixon short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.

‡‡ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.

§§ Dixon short-term Biogas and SCM site liquid hog manure 2X treatment.

¶¶ Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.

Melfort site control treatment.

††† Melfort site liquid hog manure 2X treatment.

‡‡‡ Melfort site urea fertilizer treatment.

In the Dixon short term biogas and SCM site, the SCM B&I 2X and SCM Injected 2X treatments showed significantly higher levels of soil P supply (3.6 and 5.7 µg cm^{-2}, respectively) compared to the control, CLH 2X and urea treatments (Figure 3.20). These significantly higher levels of soil P supply in the cattle manure treatments compared to the control, liquid hog manure and commercial urea treatments are a result of the SCM adding higher amounts of soluble P. This is in contrast to N in which the organic N in the SCM takes a longer period of time to be mineralized. Greater retention of P in the soil or enhanced mineralization of organic P in the injected 2X treatment could have allowed for a greater amount of P supply to be made available compared to the SCM B&I 2X treatment. At the Dixon LT site, the LTH NO_3-N supply was found to be slightly greater than the control and urea fertilizer treatments. The P supply was found to be lower than the control treatment. Lower P supply rates in urea treatments compared to manure treatment at all sites is consistent with gradual soil P depletion in urea fertilized plots over time, and is in agreement with lower extractable residual P levels found in the soil samples removed from the field in the fall (see section 3.1).

Soil Physical Properties

Soil Organic Carbon (SOC)

Soil organic carbon concentration (SOC) was found to be higher in the LTH 2X and LTC B&I 2X treatments at the Dixon long-term site for the 0-15 cm depth compared to the control and urea fertilizer treatments (Figure 3.21). Although not significantly higher, the higher SOC values in the LTH 2X and LTC B&I 2X treatments shows that 12 years of application of swine and cattle manure have had some effect on increasing SOC at the long-term site. Increases in SOC for the LTH 2X treatment would be made indirectly by plant uptake of the nutrients contained in the hog manure. This would have enabled plants to increase the below ground organic matter. The cattle manure contains more solid material in the form of feces, straw, bedding, and unconsumed feed. This material would directly add to the SOC pool. Plant uptake of nutrients cycled from the manure and used to produce shoot and root biomass would allow for indirect addition.

At the Dixon short-term biogas and SCM Injected site, the CLH 2X and urea fertilizer treatments had the highest SOC compared to the control treatments and the SCM treatments (Figure 3.12). The nutrients contained in the CLH 2X and nitrogen contained in the commercial urea fertilizer would be readily available for plant uptake and production of organic matter. There are more organic nutrients contained in the SCM and more time is need to cycle them into plant available forms. There has been only two years of SCM application on the short-term site.

Figure 3.21. Soil organic carbon concentration (%C) at 0-15 cm depth from intact soil cores at the Dixon long-term and short-term sites and Melfort site.

† Dixon long-term hog and cattle manure site disturbed control treatment.

‡ Dixon long-term site liquid hog manure 2X application treatment.

§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.

¶ Dixon long term site urea fertilizer 2X treatment.

Dixon short-term Biogas and SCM site disturbed control treatment.

†† Dixon short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.

‡‡ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.

§§ Dixon short-term Biogas and SCM site liquid hog manure 2X treatment.

¶¶ Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.

Melfort site control treatment.

††† Melfort site liquid hog manure 2X treatment.

‡‡‡ Melfort site urea fertilizer treatment.

When compared to the long-term SCM application, it can be seen that a longer time period is necessary to achieve major increases in SOC (Figure 3.21). The SCM Injected 2X treatment has a lower SOC concentration compared to the SCM B&I 2X treatment. This could be due to injection stimulating decomposition by improving microbial contact and moisture connditons for decomposition. The SCM B&I 2X treatment is surface applied and then incorporated by a disc. Some of the manure would be incorporated while some of the material would be left on the soil surface. This would increase the above ground portion of the SOC as there would be less material to decompose compared to the subsurface injected treatment.

The Melfort site had higher SOC concentrations compared to both Dixon sites. There were no significant differences in SOC between the control, LHM 2X and commercial urea treatments, although there was a trend for the manure and urea treatments to contain more SOC. The Melfort site is located in the Black soil zone of Saskatchewan. This site has a high content of SOC to begin with, as evidenced by the control treatment having only slightly less SOC versus the other two treatments. Although not significantly different, the LHM and commercial urea treatments do show an increase in SOC from 3.6 % in the control treatment to 4.0% for the LHM 2X and urea fertilizer treatments (Figure 3.12).

Sodium Adsorption Ratio (SAR)

Measurement of sodium adsorption ratios for the Dixon long-term site reveal that the LTH 2X and LTC 2C treatments had higher SAR values compared to the control and urea fertilizer treatments (Figure 3.22). The Dixon short-term biogas and SCM site also showed increased SAR values with the addition of CLH 2X and urea fertilizer. The addition of SCM either by B&I or subsurface injection resulted in higher SAR values compared to the CLH 2X, urea fertilizer and control treatments. The Melfort site had the lowest SAR values amongst the three sites. The LHM 2X treatment had the largest increase in SAR and was significantly higher than the control and urea fertilizer treatments (Figure 3.22).

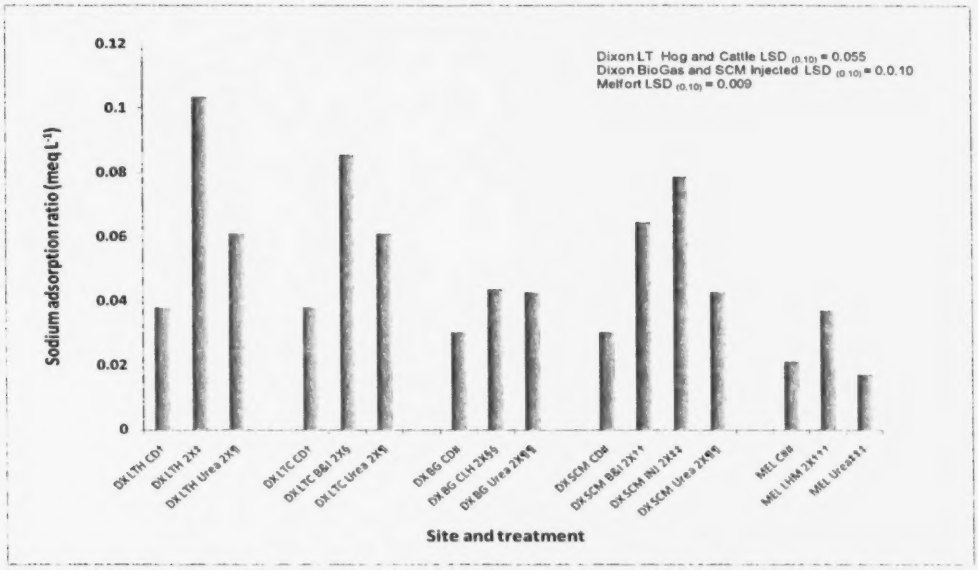


Figure 3.22 Sodium adsorption ratio at 0-15 cm depth determined from intact soil cores at the Dixon long-term and short-term sites and Melfort site.

† Dixon long-term hog and cattle manure site disturbed control treatment.
‡ Dixon long-term site liquid hog manure 2X application treatment.
§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.
¶ Dixon long term site urea fertilizer 2X treatment.
# Dixon short-term Biogas and SCM site disturbed control treatment.
†† Dixon short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.
‡‡ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.
§§ Dixon short-term Biogas and SCM site liquid hog manure 2X treatment.
¶¶ Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.
Melfort site control treatment.
††† Melfort site liquid hog manure 2X treatment.
‡‡‡ Melfort site urea fertilizer treatment.

The lower initial SAR values in the control treatment at Melfort suggest that this site had lower SAR values at the initiation of the LHM study compared to the Dixon site. Addition of manure appears to cause some small increases in sodicity but overall the SAR values are very low, considering that a SAR value of greater than 13 designates a soil as being sodic. Therefore, soil sodicity arising from manure application that would be of concern to soil structure does not appear to be an issue here.

Modulus of Rupture (Soil Strength)

Although not significantly different from the control treatment and either the LTH 2X or LTC 2X treatments, the application of urea fertilizer increased mean soil strength at the Dixon long-term site slightly from 9.6 kPa in the control treatment to 15.5 kPa in the urea fertilizer treatment (Figure 3.23). Comparing the application of liquid swine manure to solid cattle manure, soil strength was found to higher in the LTH 2X treatment (11.4 kPa) compared to the

LTC 2X (7.1 kPa) treatment. This is consistent with slightly greater sodicity observed in the LTH treatment compared to the LTC treatment.

Soil strength was found to be the lowest of the three sites in the Dixon short-term biogas and SCM Injected plots. There were no significant differences to be found between treatments at the Dixon short-term site. These sites have the shortest time period of application. While the Dixon LT manure application may increase sodicity and soil strength slightly, similar effects were found in the urea treatment.

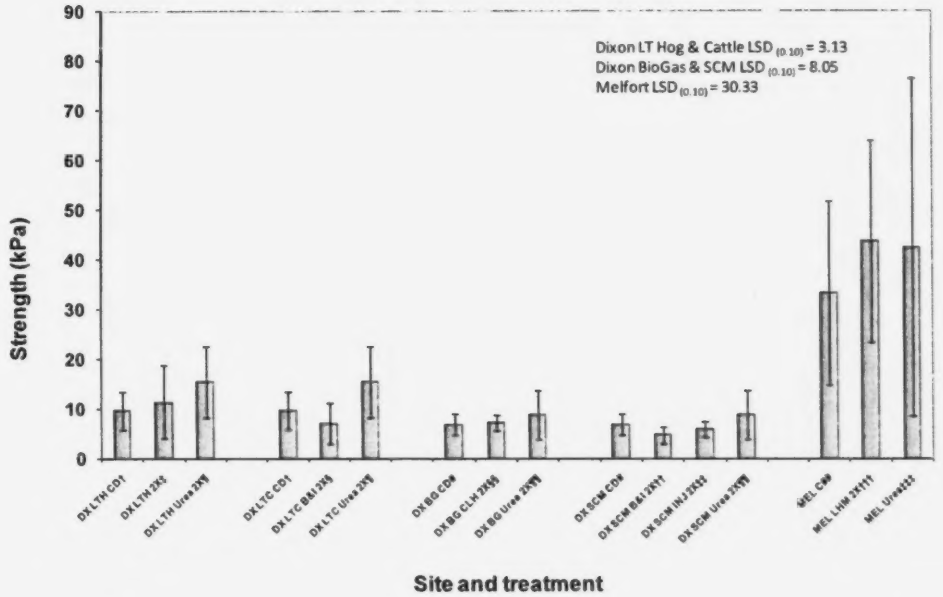


Figure 3.23 Modulus of rupture (soil strength) at 0-15 cm depth from intact soil cores at the Dixon long-term and short-term sites and Melfort site.

† Dixon long-term hog and cattle manure site disturbed control treatment.

‡ Dixon long-term site liquid hog manure 2X application treatment.

§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.

¶ Dixon long term site urea fertilizer 2X treatment.

Dixon short-term Biogas and SCM site disturbed control treatment.

†† Dixon short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.

‡‡ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.

§§ Dixon short-term Biogas and SCM site Cudworth liquid hog manure 2X treatment.

¶¶ Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.

Melfort site control treatment.

††† Melfort site liquid hog manure 2X treatment.

‡‡‡ Melfort site urea fertilizer treatment.

Of note is that the Melfort site had significantly higher soil strength compared to the two Dixon sites. Soil strength in the Melfort control treatment was 33.2 kPa, compared to 9.6 and 6.9 in the Dixon long-term and short-term respectively treatments (Figure 3.23). Although not significantly ($p<0.10$) different, the application of LHM 2X and urea fertilizer further increased soil strength to 43.7 and 42.5 kPa , respectively. The major difference in soil strength at the Melfort site, when compared to both Dixon sites could be related to the fact that Melfort has a greater amount of clay (26% clay at Melfort versus 8% at Dixon), which tend to develop greater cohesive forces among particles. The Melfort site also had a greater amount of soil moisture present compared to the Dixon site in the fall of 2008 when the intact soil cores were obtained, would have led to greater compaction within the core during sampling.

Coefficient of Linear Extensibility (COLE)

The Dixon long-term site showed no significant differences in COLE amongst the treatments (Figure 3.24). The Dixon LTH 2X treatment showed the highest, although not significantly higher COLE at 0.069. The LTC 2X treatment showed the lowest COLE of 0.058. The Dixon short-term biogas and SCM site showed no significant differences in COLE values amongst the treatments. The highest COLE was found in the SCM Injected 2X treatment, while the control and urea fertilizer treatments had COLE values of 0.051. The Melfort site had the highest overall COLE values compared to both Dixon sites. There were, however, no significant differences between the three treatments at the Melfort site. Work conducted 4 years previously did show differences in COLE between urea and LHM treatments at the Melfort site. The higher clay content at Melfort would allow for greater shrink-swell potential compared to both Dixon LT and ST sites, explaining higher overall COLE values at Melfort.

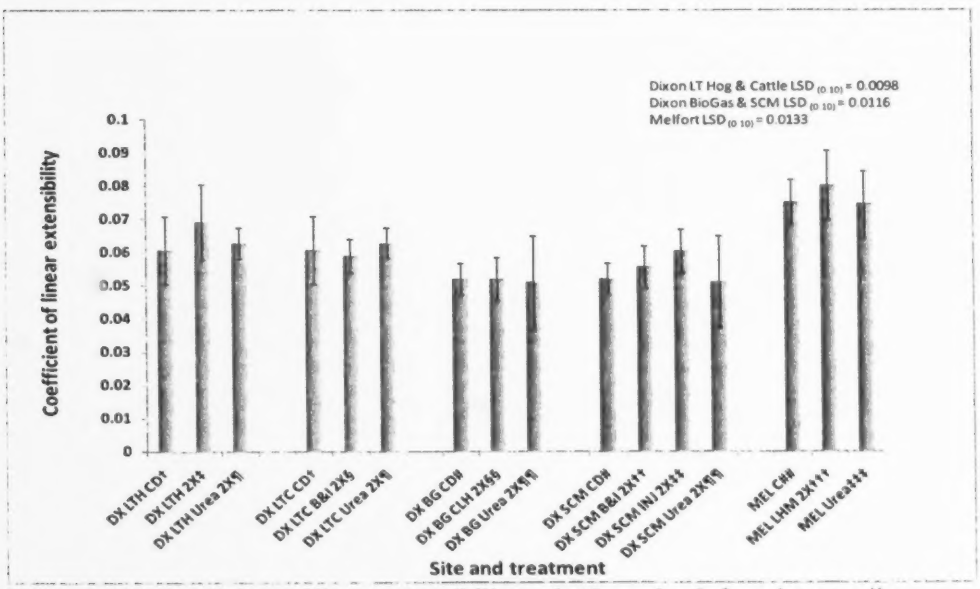


Figure 3.24. Coefficient of linear extensibility at 0-15 cm depth from intact soil cores at the Dixon long-term and short-term sites and Melfort site.

† Dixon long-term hog and cattle manure site disturbed control treatment.

‡ Dixon long-term site liquid hog manure 2X application treatment.
§ Dixon long-term site solid cattle manure broadcast and incorporated 2X application treatment.
¶ Dixon long term site urea fertilizer 2X treatment.
# Dixon short-term Biogas and SCM site disturbed control treatment.
†† Dixon short-term Biogas and SCM site solid cattle manure broadcast and incorporated 2X application treatment.
‡‡ Dixon short-term Biogas and SCM site solid cattle manure subsurface injected 2X application treatment.
§§ Dixon short-term Biogas and SCM site liquid hog manure 2X treatment.
¶¶ Dixon short-term Biogas and SCM site urea fertilizer 2X treatment.
Melfort site control treatment.
††† Melfort site liquid hog manure 2X treatment.
‡‡‡ Melfort site urea fertilizer treatment.

4. CONCLUSIONS

2007-2009 Field Experiments

The field experiments conducted: 1) Dixon short-term raw liquid swine manure versus biodigestate; 2) Dixon long-term liquid swine manure; 3) Dixon long-term solid cattle manure and 4) Melfort long-term liquid swine manure were useful in revealing the implications of short-term (1-3 yrs) versus long-term (>10 yrs) repeated additions of different manure sources to Saskatchewan soils. Per unit of nutrient added, there appears to be little difference in the agronomic effects of biodigestate left after biogas production from liquid swine manure versus the raw liquid swine manure feedstock itself. Although the nutrient contents were variable, per unit of nutrient they had similar effects on yields, crop nutrient concentration and uptake and soil nutrients and other attributes over the three years of the study. Rates of raw liquid swine manure or biodigestate of 3000-4000 gallons per acre (~75-100 lbs N / acre /yr) per year gave optimum yields of the oats and canola grown over the three years and did not result in excessive soil nutrient loading. As anticipated, application of swine manure at these rates over three years had little impact on soil properties like pH, salinity and organic carbon compared to the urea fertilized treatments and the unfertilized control.

In the long-term (>10 yrs) liquid swine manure trials, the last three years that are examined in this study (2007,2008 and 2009) reveal similar effects on crops and soils as has been observed in previous years. Application rates of 3000 – 4000 gallons per acre every year (~75 – 100 lbs N / acre / yr) gave near optimal yields for the crops examined (oats, canola, barley) and were not associated with any loading of nitrate or phosphate in the soil. As such, these rates of application are again confirmed as the "agronomic" optimum. Double these rates applied every second year also gave good yield response in the year of application, and provided significant residual benefits in the second year after application. However, especially in the moister environment encountered at Melfort, yields in the second year following application were not equivalent to the annual application rate, indicated that larger applications intended to carry through for subsequent years may not be as efficient. High rates of liquid swine manure applied annually re 2X (~6600 gpa) and especially 4X (13,200 gpa) often did not produce significant yield benefit above the 1X rate and lead to accumulation of excessive quantities of nitrate in the soil profile (0-60cm) and beneath. Furthermore, 4X rates of liquid swine manure

and urea increased soil salinity slightly. Owing to the relatively low phosphorus content of the liquid swine manure, levels of soil test extractable P were only elevated significantly in the 4X rates. Nitrate accumulation rather than P loading is of more concern with excessive application of this swine manure. The effect of nitrification of ammonium derived from the liquid swine manure or urea fertilizer was evident in lower surface soil pH in high rate annual additions of liquid swine manure or urea. Therefore, soil acidity and salinity may be other adverse effects of excess application (200 + lbs N/acre/yr) of liquid swine manure or urea.

In 2007, 2008 and 2009, the injection application of the liquid swine manure resulted in significantly higher yield and N recovery by the crop compared to broadcast and incorporate applications. Injection of liquid swine manure therefore is confirmed again to reduce overall gaseous N loss potential and also may improve root access to nutrients. It was also noted, based on yield response to banding of commercial P fertilizer observed only in the broadcast and incorporate treatment, that injection of liquid swine manure also appears to improve crop access to manure phosphorus. Therefore injection appears to be a means to more effectively utilize both N and P contained in liquid swine manure. As observed in all previous years, the addition of the nitrification inhibitor DCD kept nitrogen in the soil in the ammonium form longer but did not appear to significantly improve crop N recovery or yield, likely because the loss potential was not high. Therefore, there would appear to be relatively little benefit on soil N recovery from adding this product to swine manure under conditions encountered in this study.

The general lack of yield response to supplemental phosphorus fertilizer observed in the swine manure treatments indicates that the P present in swine manure is sufficient to supply the P needed by crops and there is no need to supply supplemental P fertilizer. However, the effect of many years of addition of urea fertilizer without any phosphorus on the drawdown of P fertility is evident in very large yield response of crops to supplemental fertilizer P on the commercial urea plots. Clearly the benefit of adding liquid swine manure as a fertilizer is not only in the N benefits but also from the other nutrients like P, K and micronutrients that it adds.

On sulfur deficient soils like the Melfort site, some benefit was observed from the addition of supplemental fertilizer sulfur along with liquid swine manure, compared to swine manure alone. However, the benefits appear to be variable and difficult to predict, as sometimes one form of sulfur was better than the other, and the benefits were sometimes greater the year after application compared to the year of application. Overall, it may be concluded that while liquid swine manure appears to supply some sulfur to crops, the addition of supplemental sulfur fertilizer may be good insurance to ensure maximum yield and alleviation of any possible S deficiency.

Since most of the nitrogen added in solid cattle manure is present in the form of organic N and is associated with a large amount of carbon, the plant availability of the nitrogen added as solid cattle manure is significantly less than for swine manure, where much of the nitrogen is present as immediately available ammonium. Due to the requirement for mineralization to slowly release organically bound N into plant available inorganic forms, higher amounts of N added as cattle manure are required to meet short-term crop N needs compared to liquid swine manure or urea. Therefore, the annual application of solid cattle manure at rates of ~ 7-15 tons of dry manure equivalent per acre per year (~150 – 300 lbs N/acre) were found to be associated with maximum yield of the oats and canola, higher than that required for liquid swine manure, so as to provide sufficient N from the manure alone. However, due to the high content of P in the solid cattle manure, this also adds ~ 80 to 140 lbs of P / acre, much more than what the crop can use. As a result, soil test extractable P levels are elevated above 100 kg MK P/ha 0-30cm in

these treatments upwards to 250 kg MK P /ha 0-30cm in the 15 tons of dry manure per acre per year treatment. To reduce problems with soil P loading, low rate (3-4 tons dry manure/acre) or less frequent application of higher rates and application according to P requirement with supplemental N fertilizer added to meet the crop N needs is recommended. Because of the low ammonium content of the solid cattle manure, the addition of the cattle manure had relatively little impact on soil pH. Similarly, because nearly all the N in the cattle manure is present in organic forms not greatly susceptible to volatile loss, there was no discernible benefit from broadcast and immediate versus broadcast and 24 hour delay in incorporation. As a result of the low N availability in the solid cattle manure, the soil nitrate contents in fall were only slightly elevated compared to the control, and less than for urea. There was no evidence of deep leaching of nitrate in the cattle manure treatments even at the high rate. The loss of nutrient from the system as phosphate with water would appear to be the major environmental consequence of over-application of cattle manure while leaching of nitrate or conversion to nitrous oxide would appear to the main nutrient escape issue with over-application of liquid swine manure.

Greenhouse Gas, Nutrient Supply Rate and Soil Physical Properties Incubation Study

In this experiment the manured and urea fertilized treatments produced low amounts of nitrous oxide gas over the ten day incubation period likely as a result of measurement at the end of the growing season several months after manure or fertilizer application was made. Urea fertilized treatments did show a trend to produce slightly more N_2O than manure treatments. History of manure application (short-term versus long-term) appeared to have little relation to N_2O production at the end of the growing season. For all three sites, carbon dioxide evolution spiked between the first 48 and 96 hours of incubation and then remained relatively stable for the remainder of the incubation period. There was little difference between either type of manure or between broadcast and incorporated or subsurface injected types of solid cattle manure application. As for N_2O, the lack of significant differences in CO_2 likely reflect the duration of several months that lapsed between last manure application in the fall of 2007 and measurement in samples collected in the fall of 2008. It appears that the effects of manure application in greenhouse gas production are most evident in the first few weeks following application and then diminish over time.

Soil supply of nitrate was found to be the greatest in the liquid swine manure, reflecting the greater amount of inorganic plant available nitrogen contained within, while solid cattle manure supplied more phosphorus, reflecting the higher phosphorus containing cattle manure. Elevated supplies of nitrate, indicative of nitrification, were consistent with increased nitrous oxide emissions arising from this source.

After 12 years of hog and cattle manure application, the Dixon long-term site has showed some small increases in soil organic carbon, but this was not evident at the Dixon short-term Biogas and SCM site. A long period of time is likely required to result in significant increases in soil organic matter. Soil organic carbon can be added directly to the soil via solid cattle manure which contains more solid organic materials such as fecal matter, bedding and straw. Liquid hog manure indirectly adds to soil organic matter by supplying plants with readily available nutrients, which allows the plants to add to both the above and below ground organic matter. The Melfort

site soil, which already has a large amount of organic matter, would need substantial annual manure applications to result in measureable significant increases in soil organic carbon.

The application of swine and cattle manure either on a long-term or short-term basis did not affect soil sodicity values to any great extent. Dixon soils are quite low in sodium, well drained and contain large amounts of calcium that likely helps to buffer any effect that adding sodium in the manure would have. Soil strength was found to be significantly greater in the Melfort soil. This was attributed to the Melfort soil having a greater amount of clay compared to the Dixon LT and ST sites.

Overall, when measured several months following the last manure application, the application of manure over the short or long-term appears to have relatively little impact in greenhouse gas production. Similarly, with the exception of phosphate for solid cattle manure, there is little influence in supplies of available nutrient. Effects on soil physical conditions are also relatively small.

Directions For Future Research

The research work that has been conducted on these long-term trials has provided key information on agronomic and environmentally sustainable manure management practices for different manure forms in both short run and long run scenarios. Monitoring of key properties affected by repeated manure application over the ten to twenty year time frame would be beneficial. Expected life of an intensive livestock operation may span 20 years or more, and this monitoring should concentrate on swine manure, as these trials are unique. There are already long-term cattle manure application trials in southern Alberta that extend beyond 20 years. Evaluation of the persistence and fate of nutrients that have accumulated from several years of manure application once application ceases should be determined, so as to determine what residual benefits may accrue that relate to assessing the value of manure, as well as how long it takes to reduce soil nutrient levels in situations (treatments) where over-application has resulted in excessive build-up.

Outputs

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J.J. Schoenau and S.S. Malhi, 2009. Swine Manure Study. Melfort Research Farm Field Day, July 17, 2009, Melfort, SK (25 present)

Two book chapters completed and in press on "Soil physical properties following long-term application of swine and cattle manure in Western Canada" and "Strategies for maximizing crop recovery of applied manure nitrogen in the Northern Great Plains" for book "Recent Trends in Soil Science and Agronomy Research in Northern Great Plains of North America"

Personnel

PhD student: T. King
Research associate: P. Qian
Research technician: C. Fatteicher

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Field signage and at end of papers and presentations

Equipment

None

Expense Statement

From Financial Services Reporting, University of Saskatchewan

APPENDIX A Manure Composition and Application Rates

2007 **Concentrations in *Hog Manure* Applied at Dixon Long-Term Crop Site in Spring 2007 for 2007 Season**

Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
----------ug/ml----------							
2068	1800	-	587	42	1200	100	200

Application rates of nutrient in kg/ha

Rate gpa							
3300	68	59		19	1.3	40	3.3	6.6

2007 **Concentrations in *Cattle Manure* Applied at Dixon Long-Term Crop Site in Spring 2007 for 2007 Season**

Tot. N	NH4	NO3	Tot. P	Soluble P
----------ug/g wet manure----------				
4793	50	-	2439	182

Application rates of nutrient in kg/ha

Rate Tons/acre (dry)					
3.5	73	0.8	-	37	2.8

2007 **Concentrations in *Hog Manure* Applied at Melfort Long-Term Crop Site in Fall 2006 for 2007 Season**

Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
ug/ml							
3775	1852	-	773	48	1800	300	400

Application rates of nutrient in kg/ha

Rate gpa								
3300	125	61	-	25	1.6	59	9.9	13.2

2007 **Concentrations in *Hog Manure* Applied at Dixon Biodigestate Site in Spring 2007 for 2007 Season**

Cudworth RAW

Tot. N	NH4	NO3	Tot. P	Soluble P
ug/ml				
2557	1018	-	554	30

Application rates of nutrient in kg/ha

Rate gpa					
1500	38	15	-	8	0.5

Cudworth BIODIGESTATE

	Tot. N	NH4	NO3	Tot. P	Soluble P
	ug/ml				
	2571	1610	-	833	34
	Application rates of nutrient in kg/ha				
Rate gpa					
1500	39	24	-	12	0.5

2008 **Concentrations in *Hog Manure* Applied at Dixon Long-Term Crop Site in Fall 2007 for 2008 Season**

Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
ug/ml							
2055	1850	-	132	25	900	400	400

Application rates of nutrient in kg/ha

Rate gpa							
3300	68	61		4	0.8	30	13	13

2008 **Concentrations in *Cattle Manure* Applied at Dixon Long-Term Crop Site in Fall 2007 for 2008 Season**

Tot. N	NH4	NO3	Tot. P	Soluble P
ug/g wet manure				
4952	12	-	2904	261

Application rates of nutrient in kg/ha

Rate Tons/acre (dry)				
3.5	75	0.2	44	4

2008 **Concentrations in *Hog Manure* Applied at Melfort Long-Term Crop Site in Fall 2007 for 2008 Season**

	Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
	ug/ml							
	2499	2268	-	227	10	1100	100	300
	Application rates of nutrient in kg/ha							
Rate gpa	82	75		8	0.3	36	3	3
3300								

2008 **Concentrations in *Hog Manure* Applied at Dixon Biodigestate Site in Fall 2007 for 2008 Season**

Cudworth RAW

	Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
	ug/ml							
	1498	804	-	578	13	500	100	<100
	Application rates of nutrient in kg/ha							
Rate gpa	22	12		8.7	0.2	8	2	< 2
1500								

Cudworth BIODIGESTATE

	Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
	----------ug/ml----------							
	1198	1020	-	402	8	600	<100	100
	Application rates of nutrient in kg/ha							
Rate gpa	18	15		6	0.1	9	<1.5	1.5
1500								

2009 Concentrations in *Hog Manure* Applied at Dixon Long-Term Crop Site in Fall 2008 for 2009 Season

Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
ug/ml							
2400	2100	-	207	5	1100	200	700

Application rates of nutrient in kg/ha

Rate gpa							
3300	79	69		7	0.2	36	6.6	23

2009 Concentrations in *Cattle Manure* Applied at Dixon Long-Term Crop Site in Fall 2008 for 2009 Season

Tot. N	NH4	NO3	Tot. P	Soluble P
ug/g wet manure				
4948	402	-	3723	156

Application rates of nutrient in kg/ha

Rate Tons/acre (dry)				
3.5	75	6	57	2

2009 **Concentrations in *Hog Manure* Applied at Melfort Long-Term Crop Site in Fall 2008 for 2009 Season**

Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
ug/ml							
2500	2200	-	160	8	1200	200	500

Application rates of nutrient in kg/ha

Rate gpa							
3300	83	73	5	0.3	40	7	17

2009 **Concentrations in *Hog Manure* Applied at Dixon Biodigestate Site in Fall 2008 for 2009 Season**

Cudworth RAW

Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
ug/ml							
6200	4400	-	591	20	2000	500	600

Application rates of nutrient in kg/ha

Rate gpa							
1500	93	66	8.9	0.3	30	8	9

Cudworth BIODIGESTATE

	Tot. N	NH4	NO3	Tot. P	Soluble P	K	S	Na
	ug/ml							
	1600	1300	-	323	8	600	<100	200
	Application rates of nutrient in kg/ha							
Rate gpa	24	20		5	0.1	9	<1.5	3
1500								

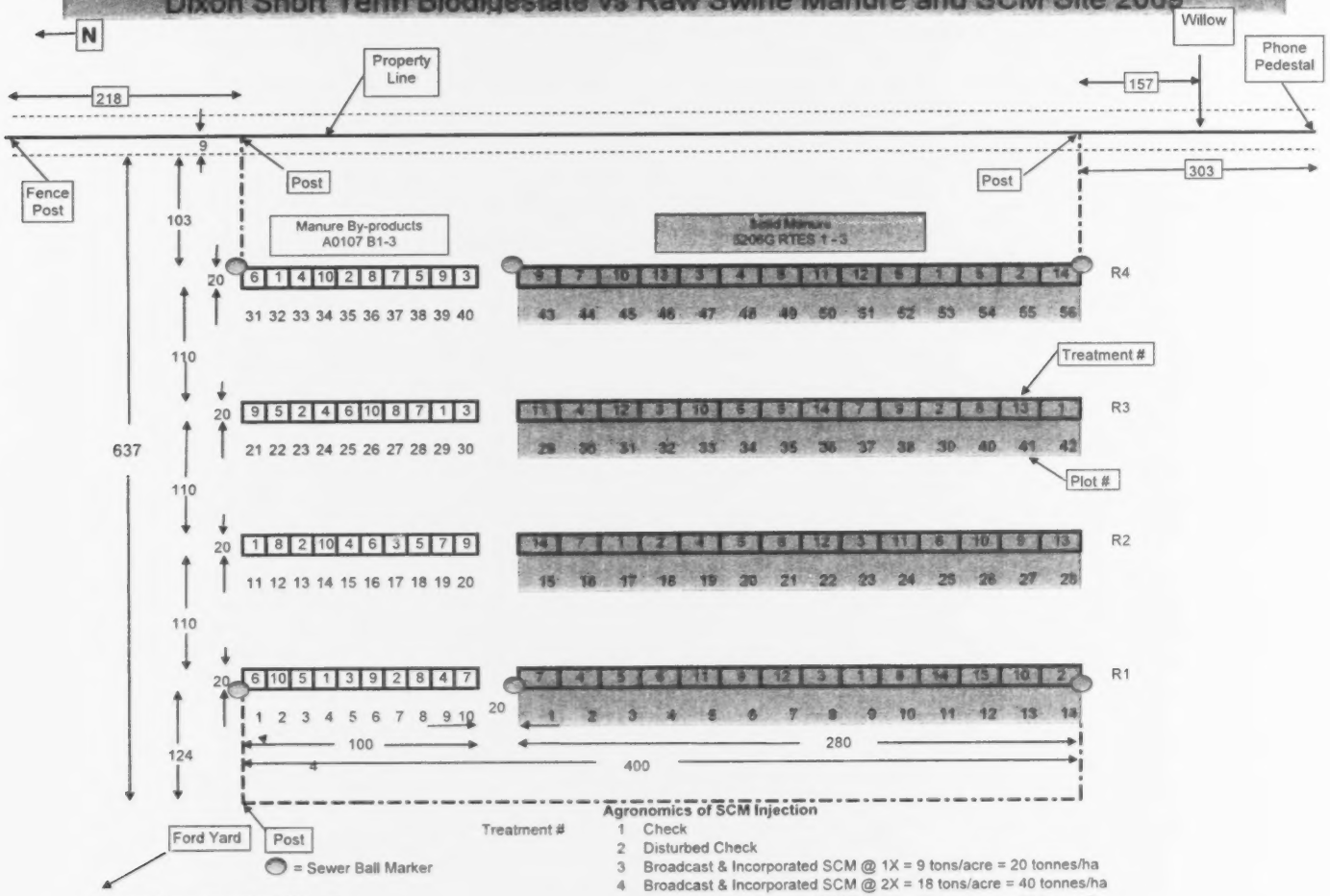
APPENDIX B 2007, 2008, 2009 CROP YIELD, NUTRIENT CONTENT, SOIL NUTRIENTS AND PROPERTIES

Data available on request

APPENDIX C FIELD PLANS OF RESEARCH SITES

Short Term Biodigestate from Liquid Swine Manure Biogas Production vs Raw Liquid Swine Manure and Short-Term Solid Cattle Manure Dixon
Dixon Long-Term Liquid Swine Manure
Dixon Long-Term Solid Cattle Manure
Melfort Long-Term Liquid Swine Manure

Dixon Short Term Biodigestate vs Raw Swine Manure and SCM Site 2009



Biodigestate vs Raw Liquid Hog Manure

Treatment #

1 Digesate @ 1X = 1500 gpa = 16800 L/ha
2 Digesate @ 2X = 3000 gpa = 33600 L/ha
3 Digesate @ 4X = 6000 gpa = 67200 L/ha
4 Urea banded @ 1X = 50 lb N/acre = 56kg/ha
5 Urea banded @ 2X = 100 lb N/acre = 112 kg/ha
6 Urea banded @ 4X = 200 lb N/acre = 224 kg/ha
7 Cudworth Raw LHM @ 1X = 1500 gpa = 16800 L/ha
8 Cudworth Raw LHM @ 2X = 3000 gpa = 33600 L/ha
9 Cudworth Raw LHM @ 4X = 6000 gpa = 67200 L/ha
10 Check

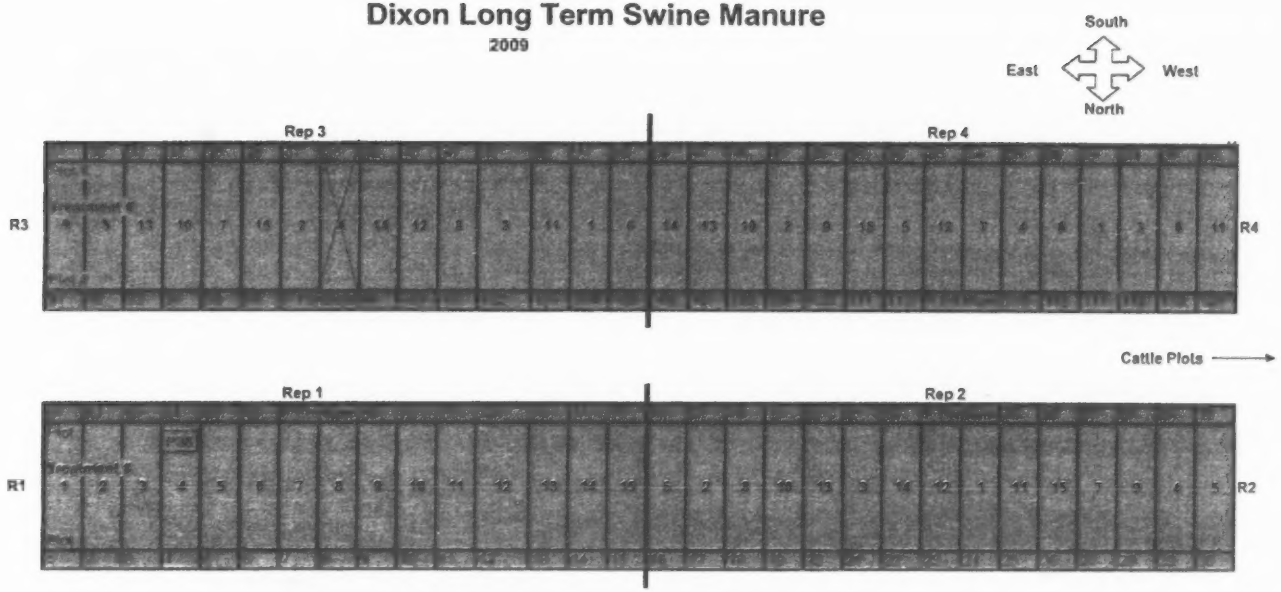
Treatment #

Agronomics of SCM Injection

1 Check
2 Disturbed Check
3 Broadcast & Incorporated SCM @ 1X = 9 tons/acre = 20 tonnes/ha
4 Broadcast & Incorporated SCM @ 2X = 18 tons/acre = 40 tonnes/ha
5 Broadcast & Incorporated SCM @ 3X = 27 tons/acre = 60 tonnes/ha
6 Broadcast & **NOT** Incorporated SCM @ 1X = 9 tons/acre = 20 tonnes/ha
7 Broadcast & **NOT** Incorporated SCM @ 2X = 18 tons/acre = 40 tonnes/ha
8 Broadcast & **NOT** Incorporated SCM @ 3X = 27 tons/acre = 60 tonnes/ha
9 Injected SCM @ 1X = 9 tons/acre = 20 tonnes/ha
10 Injected SCM @ 2X = 18 tons/acre = 40 tonnes/ha
11 Injected SCM @ 3X = 27 tons/acre = 60 tonnes/ha
12 Injected SCM @ 1X = 9 tons/acre + 70 lbs/acre banded urea N fertilizer
= 20 tonnes/ha manure + 78 kg/ha banded Urea fertilizer
13 Injected SCM @ 2X = 18 tons/acre + 70 lbs/acre banded urea N fertilizer
= 40 tonnes/ha manure + 78 kg/ha banded Urea fertilizer
14 Injected SCM @ 3X = 27 tons/acre + 70 lbs/acre banded urea N fertilizer
= 60 tonnes/ha manure + 78 kg/ha banded Urea fertilizer

Dixon Long Term Swine Manure

2009



Treatments	F 96	F 97	F 98	F 99	F 00	F 01	F 02	F 03	S05	F 05	S07	F07	F08
	S 97	S 98	S 99	S 00	S 01	S 02	S 03	S 04	S 05	S 06	S07	S08	S09
1. Check-No Injector Pass	0X	0X	0X	0X	0X	0X	0X	0X	0X	0X	0X	0X	0X
2. Check- Injector Pass at 12"	0X	0X	0X	0X	0X	0X	0X	0X	0X	0X	0X	0X	0X
3. Injector 12"	1X	0X	0X	1X	0X	0X	1X	0X	0X	1X	0X	0X	1X
4. Injector 12"	1X	1X	1X	1X	1X	1X	1X	1X	1X	1X	1X	1X	1X
5. Injector 12"	2X	0X	0X	2X	0X	0X	2X	0X	0X	2X	0X	0X	2X
6. Injector 12"	2X	0X	2X	2X	0X	2X	0X	2X	0X	2X	0X	2X	0X
7. Injector 12"	2X	2X	2X	2X	2X	2X	2X	2X	2X	2X	2X	2X	2X
8. Injector 12"	4X	0X	0X	4X	0X	0X	4X	0X	0X	4X	0X	0X	4X
9. Injector 12"	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X
10. Injector 12" DCD N Inhib.	1X	1X	1X	1X	1X	1X	1X	1X	1XN	1XN	1XN	1XN	1XN
11. Manure/Water 3,300 gpa	1X	1X	1X	1X	1X	1X	1XW	1XW	1XW	1XW	1XW	1XW	1XW
12. Broadcast and Inc.	1X	1X	1X	1X	1X	1X	1X	1X	1X	1X	1X	1X	1X
13. Banded Urea	1X	1X	1X	1X	1X	1X	1X	1X	1X	2X*	1X	1X	1X
14. Banded Urea	2X	2X	2X	2X	2X	2X	2X	2X	2X	2X	2X	2X	2X
15. Banded Urea	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X

Manure and Water Application
1X = 3,300 gpa (37,000 l/ha)
2X = 6,600 gpa (74,000 l/ha)
4X = 13,200gpa (148,000 l/ha)

Commerical Fertilizer Urea Application
1X = 50 lb N/ac (56 kg N/ha)
2X = 100 lb N/ac (112 kg N/ha)
4X = 200 lb N/ac (224 kg N /ha)

Note: = Hog Manure Regular Plots
Note: = Hog Manure + Phosphorus Fertilizer Plots
Note: =Treatment #10 now 12" and has DCD N Inhibitor added in Spring 2005
Note: = Old Plot 38. Deactivated until ~2010
Note: = Location of "New" Plot 38 (at south end of Plot 4)
F = Fall season
S = Spring season

Dixon Long Term Solid Cattle Manure

2009

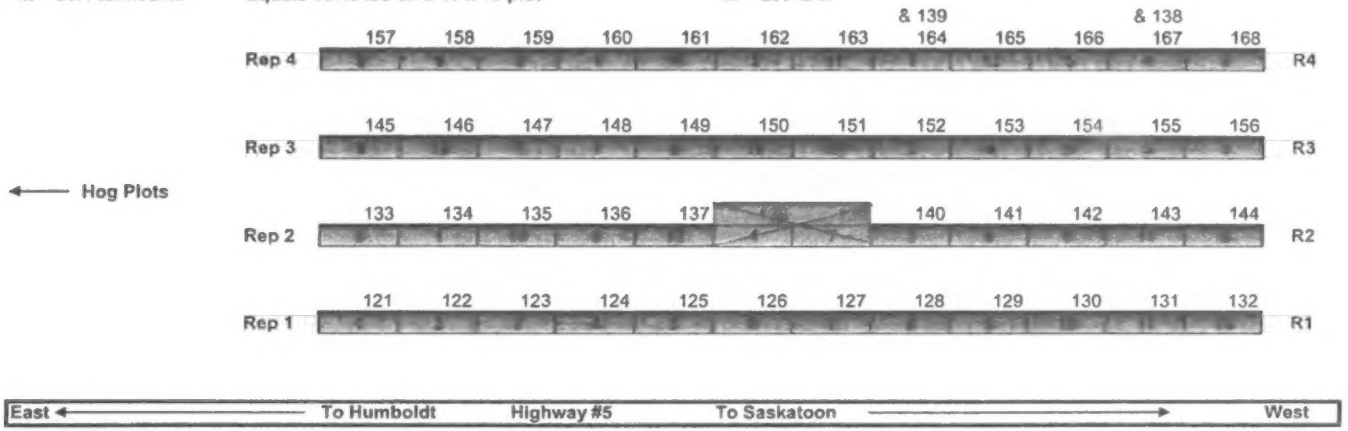
South / East / West / North

Treatments	F 1996	F 1997	F 1998	F 1999	F 2000	F 2001	F 2002	F 2003	F 2004	F 2005	S 2007	F 2007	F2008
	S 1997	S 1998	S 1999	S 2000	S 2001	S 2002	S 2003	S 2004	S 2005	S 2006	S 2007	S2008	S2009
1. Check -Incorporated	0x	0x	0x	0x	0x	0x	0x	0x	0x	0x	0x	0x	0x
2. Broad & Incorp	1x	0x	0x	1x	0x	0x	1x	0x	0x	1x	0x	0x	1x
3. Broad & Incorp	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x
4. Broad & Incorp	2x	0x	0x	2x	0x	0x	2x	0x	0x	2x	0x	0x	2x
5. Broad & Incorp	2x	0x	2x	2x	0x	2x	0x	2x	0x	2x	0x	2x	0x
6. Broad & Incorp	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x
7. Broad & Incorp	4x	0x	0x	4x	0x	0x	4x	0x	0x	4x	0x	0x	4x
8. Broad & Incorp	4x	4x	4x	4x	4x	4x	4x	4x	4x	4x	4x	4x	4x
9. Broad Delayed Incorp	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x	1x
10. Urea	1x	1x	1x	1x	1x	1x	1x	1x	1x	2X*	1x	1x	1x
11. Urea	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x	2x
12. Urea	4x	4x	4x	4x	4x	4x	4x	4x	4x	4x	4x	4x	4x

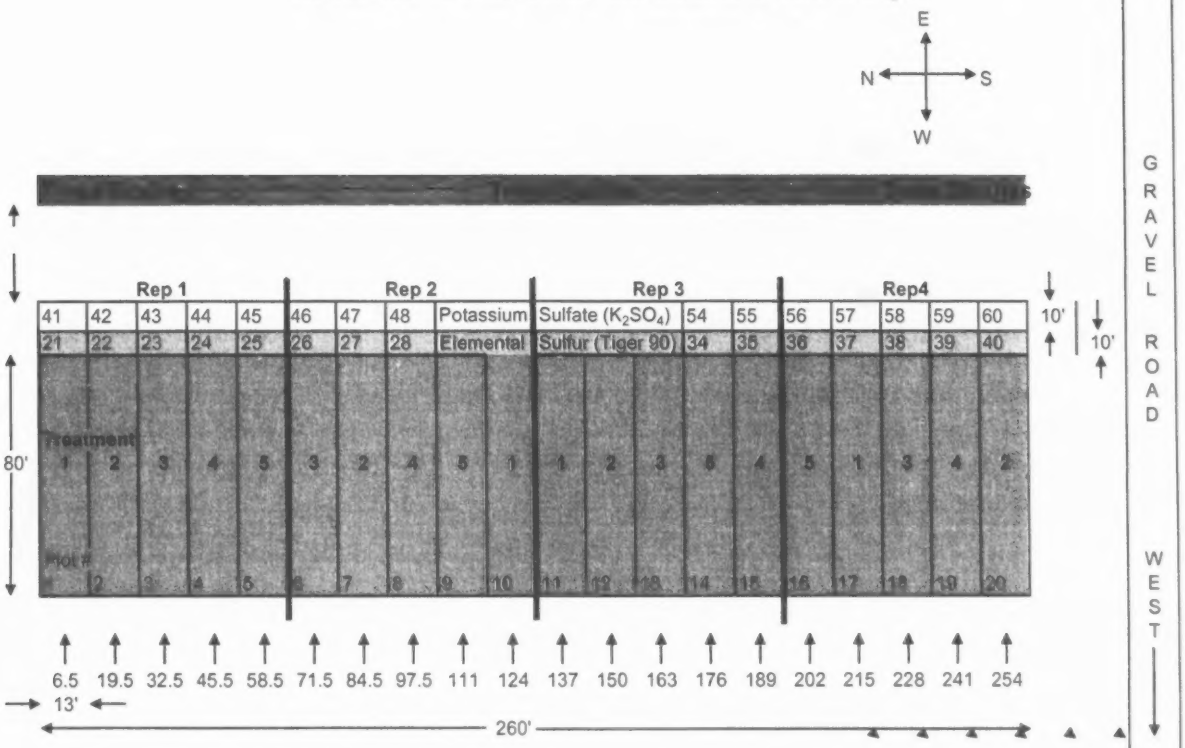
Cattle Manure
1x = 7.6 tonnes/ha — Equals 40.4 lbs on a 10 x 10 plot
2x = 15.2 tonnes/ha — Equals 80.8 lbs on a 10 x 10 plot
4x = 30.4 tonnes/ha — Equals 161.6 lbs on a 10 x 10 plot

Urea
1x = 50 lb N
2x = 100 lb N
4x = 200 lb N

F = Fall Application
S = Cropping Season



Melfort LT Swine Manure Plot Map



Treatments (applied in Fall for next year cropping season, unless otherwise noted)

	Fall 1999	Fall 2000	Fall 2001	Fall 2002	Fall 2003	Fall 2004 Spring 05	Fall 2005	Fall 2006	Fall 2007	Fall 2008
T1	Check	Check	Check	Check	Check	Check	Check	Check	Check	Check
T2	3000 gpa	3000 gpa	3000 gpa	3300 gpa	3300 gpa	3300 gpa	3300 gpa	3300 gpa	3300 gpa	3300 gpa
T3	6000 gpa	No Appl.	6000 gpa	No Appl.	6600 gpa	No Appl.	6600 gpa	No Appl.	6600 gpa	No Appl.
T4	9000 gpa	No Appl.	No Appl.	9900 gpa	No Appl.	No Appl.	9900 gpa	No Appl.	No Appl.	9900 gpa
T5	Urea	Urea	Urea	Urea	Urea	Urea	Urea	Urea	Urea	Urea

Note: Elemental S and K2SO4 applied at rates of 40 kg S/ha each, in Spring 2008 (no application for 2006 & 2007 crop year)
Note: For 2005, Manure and urea fertilizer not applied until Spring 2005 (should have been applied Fall 2004)
Note: Elemental S and K2SO4 applied at rates of 40 kg S/ha each, in Spring 2005 (no application for 2006 crop year)
Note: For 2002: Commercial Fertilizer Subpots at Melfort Hog manure study
Note: Plots 41-60- A Strip ~ 10 feet wide of K2S04 (Potassium sulfate) at a rate of 40 kg S/ha broacast prior to seeding
Note: Plots 21-40- A Strip ~ 10 feet wide of Elemental sulfur (Tiger 90) at at a rate of 40 kg S/ha
Note: The Sulfur strips are located at the back (east end) of the plots
Note: Distances are in feet
Note: Each plot is 13 feet wide. Ag Canada center marks the plot locations
Note: Urea applied at a rate of 80 kg N/ha (71 lbs N/ac)

Manure
1X 3300 gpa (37,000 L/ha)
2X 6600 gpa (74,000 L/ha)
3X 9900 gpa (148,000 L/ha)